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Computer Program for Analysis of High Speed, Single Row, Angular Contact, Spherical Roller Bearing, SASHBEAN
Volume I: User's Guide

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PREFACE

This report is the first of the two volume documentation for the bearing analysis computer program SASHBEAN. This volume, Volume-I, provides the detailed instructions required to successfully install and effectively use the software for the design and analysis of single row, angular contact, spherical roller bearings. The mathematical details of this analysis have been left out of this volume for the sake of simplicity and clarity. A separate volume, Volume II, provides the details of the underlying mathematical formulation and analysis for this computer program.

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1.0 INTRODUCTION

The computer program SASHBEAN (Sikorsky Aircraft Spherical Roller High Speed Bearing Analysis) analyzes and predicts the operating characteristics of a Single Row, Angular Contact, Spherical Roller Bearing (SRACSRB). The program runs on an IBM or IBM compatible personal computer, and for a given set of input data analyzes the bearing design for it's ring deflections (axial and radial), roller deflections, contact areas and stresses, induced axial thrust, rolling element and cage rotation speeds, lubrication parameters, fatigue lives, and amount of heat generated in the bearing. The dynamic loading of rollers due to centrifugal forces and gyroscopic moments, which becomes quite significant at high speeds, is fully considered in this analysis.

For a known application and it's parameters, the program is also capable of performing steady-state and time-transient thermal analyses of the bearing system. The steady-state analysis capability allows the user to estimate the expected steady-state temperature map in and around the bearing under normal operating conditions. On the other hand, the transient analysis feature provides the user a means to simulate the "lost lubricant" condition and predict a time-temperature history of various critical points in the system. The bearing's "time-to-failure" estimate may also be made from this (transient) analysis by considering the bearing as failed when a certain temperature limit is reached in the bearing components.

The program is fully interactive and allows the user to get started and access most of its features with a minimal of training. For the most part, the program is menu driven, and adequate help messages have been provided to guide a new user through various menu options and data input screens. All input data, both for mechanical and thermal analyses, are read through graphical input screens, thereby eliminating any need of a separate text editor/word processor to edit/create data files. Provision is also available to select and view the contents of output files on the monitor screen if no paper printouts are required.

A separate volume (Volume-II) of this documentation describes, in detail, the underlying mathematical formulations, assumptions, and solution algorithms of this program.

2.0 MINIMUM HARDWARE REQUIREMENT

The following is the minimum hardware configuration required to install and efficiently run the software:

An IBM or IBM compatible 286 or 386 class PC with,

a. A 80287 (for a 286 PC) or a 80387 (for a 386 PC) Math (Floating Point) co-processor. The software has been compiled and linked to run on a 286/386 PC with a Math co-processor. A version capable of running on a PC without a Math co-processor can be provided. It should be noted that a considerable loss of execution speed takes place when run on such a machine (with no math co-processor).

b. An EGA or VGA color monitor hooked-up to the PC. Though the program would run fine with a monochrome monitor, the graphical interface is most functional and most easily used with color monitors.

c. A connected printer for obtaining paper print-outs of the output results files, if required. When no hard copies are needed, the program has provisions to display and view the selected file(s) directly on the monitor screen.

Due to the extensive floating point computations involved in the program's numerical schemes, it is recommended to install and use the software on a 386 processor PC with a 80387 math co-processor.

3.0 SOFTWARE INSTALLATION

The full software package comprises of 60 files (including 36 source code files) and takes about 670 KB of disk storage. The SASHBEAN program can be installed and used either on a hard disk drive system or on a floppy disk for computers with no hard disk. The following sections describe, step-by-step, the installation and setup procedure.

3.1 INSTALLATION ON A HARD DRIVE SYSTEM

It is recommended to ensure a minimum of 1.0 MB of free disk space available on the hard disk before proceeding with the installation. The program files take up about 670 KB of disk storage, and the rest of the space will be needed for your input/output data files. The following steps provide one way to check the amount of free space available on your computer's hard disk. The following instructions assume that your hard disk is designated as the C: drive. If otherwise, replace the letter C by the actual drive letter designation for your system:

(i) At the DOS prompt type C: and press ENTER key to make the C: drive as your default drive.

(ii) At the DOS prompt type *CD/ followed by the ENTER key* to change to the root (top) directory of the C: drive.

(iii) At the DOS prompt type DIR and press ENTER. This will display a list of files and sub-directories. At the end of this list, DOS will also display a one line message indicating the total number of files and the number of free storage bytes available on the disk. (1024 Bytes = 1 KB; 1024 KB = 1 MB)

(iv) If the number of free storage bytes available is less than the suggested 1 MB, you may have to remove some of your existing files/directories from C: drive to open up enough storage before proceeding with the software installation.

Refer to Appendix A for a quick reference on some commonly used DOS commands you may need for deleting/copying files from your C: drive. Having opened up enough free space on you hard disk, you may now proceed with software installation by following these

steps. All commands, shown in bold typeface, are to be entered at the DOS prompt:

(i) Type **C:** and press ENTER key to make the C: drive as your default drive.

(ii) Type **MKDIR \SASHBEAN** and press ENTER key to create a new sub-directory, named SASHBEAN, under the root directory of the C: drive.

(iii) Type **CD \SASHBEAN** and press ENTER key to make the SASHBEAN sub-directory as your working directory.

(iv) Set the appropriate (5 1/4" or 3 1/2") software distribution disk in the A: drive of the PC.

(v) Type **COPY A:*.*** and press ENTER key. This command will copy all the program files from the "Distribution Disk" on to you hard drive in the sub-directory SASHBEAN.

(vi) After all the files have been copied over, DOS would display a completion message to this effect. Your installation is now complete. The original "Distribution Disk" may now be removed from the A: drive and put aside for safe storage.

3.2 INSTALLATION ON A FLOPPY DRIVE SYSTEM

You need at least one 5 1/4" or 3 1/2" High Density (HD) floppy drive on your computer system to efficiently run the software. Follow the following steps to install the software on a floppy disk:

(i) Format a new (or old) High Density floppy disk with the /S option using the DOS "Format" command. PLease refer to Appendix A for help on DOS formatting commands.

(ii) Using either the DOS "COPY" command or any other DOS utility program, copy all of the files from one of the software "Distribution" disks to the newly prepared (formatted with the /S option) disk. Please refer to Appendix A for help on DOS copying commands.

(iii) After all the files have been copied over to the newly formatted disk, your software installation is complete. The original "Distribution Disk" may be put aside for safe storage

4.0 PROGRAM EXECUTION

4.1 RUNNING OFF A HARD DRIVE INSTALLATION

Assuming that the hard disk on your computer is designated as the C: drive and the software is installed in a sub-directory called SASHBEAN, the following steps allow you to run the program. All commands are to be entered at the DOS prompt:

(i) Type **C:** and press ENTER. This would make the C: drive as your default drive.

(ii) Type **CD \SASHBEAN** to set the sub-directory SASHBEAN as your the working directory.

(iii) Type **SASHBEAN** and press ENTER. This would start the program execution. The program starts by displaying a title screen. Press any key to clear the title screen and display the main menu. The various options available from the main menu and it's sub-menus are described in detail in later sections.

4.2 RUNNING OFF A *FLOPPY DRIVE INSTALLATION*

On a floppy drive system, the program may either be run from A: drive on a single drive system or from A: or B: drive on a two floppy drive system. The following steps would allow you to run the program. Use of A: drive has been assumed. All commands are to be entered at the DOS prompt:

(i) Set the software installed floppy disk in the A: drive.

(ii) Type **A:** and press ENTER to make the A: drive as your default drive.

(iii) This step is same as step (iii) of section 4.1 above.

5.0 DATA FILES AND THEIR NOMENCLATURE

Most input/output of the SASHBEAN computer program takes place through the use of disk files. For example, in data preparation mode, the program interactively reads data from the user and writes it to a disk file. Similarly, the output from either a mechanical or a thermal analysis is also written to an output file on the disk. Some of these output results may also be displayed on the monitor screen during computations. These data files are TEXT (ASCII) files and are readable/printable using DOS commands and/or utilities. SASHBEAN too has provisions to list, select and display these result files on the monitor screen. The following sections, after a brief general description of DOS files and it's naming rules, describe the SASHBEAN data (input and output) files in detail.

5.1 DOS FILES AND FILENAMES

Like each folder in a file cabinet has a label, each file on a disk has a name. This name is made of two parts: a *filename* and an *extension*. DOS allows from one to eight characters long *filenames*. These could be typed either in uppercase or in lowercase. DOS converts all the filenames to uppercase. The *extension* consists of a period followed by one, two, or three characters. These extensions are very useful and often used for describing the contents of a file. A DOS filename thus looks like this:

ARTBRG.DAT

filename ——————↑ ↑—————— *extension*

Though most of the filenames will contain only letters and numbers, you may use any of the following characters to build your filenames:

A-Z a-z 0-9 $ % ' - @ { } ~ ` ! ( ) &

Some of the special characters, shown above, in your filenames may not be acceptable to the DOS utilitity programs you may want to use on these files. To play safe, use only letters and numbers to build your filenames. Also do not use any of the DOS "Reserved" words as your filenames. These words indicate special devices and are AUX, CLOCK$, COM, CON, LPT, LST, NUL, and PRN.

5.2 SASHBEAN DATA FILES AND FILENAMES

Different extensions have been used in SASHBEAN to identify different types of data files. These data files and their asso-

ciated filename extensions are listed in Table 5.1. When prompted for a filename by the program, you may enter up to eight characters for the filename. The appropriate extensions (along with the period) are not expected from the user and are appended automatically by the computer program.

	DATA FILE TYPE	EXTENSION
(a)	Input Data for Mechanical Analysis	.INP
(b)	Output Results from Mechanical Analysis	.OUT
(c)	Input Data for Steady-State Thermal Analysis	.HT1
(d)	Input Data for Transient Thermal Analysis	.HT2
(e)	Output Results from Thermal Analysis (Both Steady-State and Transient)	.HT3
(f)	Temporary Data File	.TMP
(g)	List of Available Data Files Prepared after a Directory Scan	.LST
(h)	List of Selected Data Files Prepared for Processing	.DAT

TABLE 5.1

5.3 TIPS ON SELECTING FILENAMES

For quick identification of all your data files related to one bearing design, you may use the same filename for the mechanical and thermal analyses input data files. For example, when preparing data for mechanical analysis (using option #1), you may enter the filename as ARTBRG. When preparing the data files for steady-state and/or transient analyses for the same bearing, you may use the same filename of ARTBRG. The program would differentiate between these three data files (with the same name) by assigning different extensions (as per Table 5.1). You would then see three separate files by the names ARTBRG.INP, ARTBRG.HT1, and ARTBRG.HT2 in your working directory. After selecting and processing these data files for analyses, the output from mechanical and thermal analyses would be written to files by the names ARTBRG.OUT and ARTBRG.HT3 respectively. As mentioned earlier, all these files are in Text (ASCII) format and are readable/printable using DOS commands/utilities.

6.0 THE MAIN MENU

The nine options available on the program's main menu are described individually in the following sections. To select an option, simply type in the option number from the keyboard. Do not press the ENTER (or RETURN) key after typing the option number. For example, to select option #3 (Run Analysis on Selected Data Files), type 3 at the keyboard. Options #1 through #4 are for the mechanical analysis of bearing designs, where as options #5 through #8 are for the thermal analysis on complete bearing systems. Option #9 exits the SASHBEAN program.

6.1 OPTION #1 (CREATE/MODIFY DATA FILES FOR MECHANICAL ANALYSIS)

Select this option to create new or modify existing data sets for mechanical analysis. On selection of this option, the main menu display is cleared and the data input screen #1 is displayed. Use of this and the subsequent input screens is described in detail in Section 7.0. You may return to the program main menu from this point by pressing the "Page Up" key on the keyboard.

To facilitate error free data preparation and entry, a data preparation form has been designed and a sample provided with this documentation (Appendix C). It is recommended to collect all the required data for this analysis on this form prior to invoking this option. Once the data form has been filled-in, select option #1 and key in the data. For quick and easy data entry, the flow of information on this form is in line with that on the data input screens of the program. A sample data form, duly filled-in with the mechanical analysis input data for the McGILL SB-1231 test bearing, is provided with this documentation as Appendix D.

6.2 OPTION #2 (SELECT DATA FILES FOR MECHANICAL ANALYSIS)

After the input data preparation is complete (using option #1), select this option to "Tag" (select) from the available data files for further processing. On selection of this option, the program scans your working directory for the available data sets for mechanical analysis (with .INP extension), and displays a list of their filenames. Up to 40 files may be displayed on this list. In case the directory scan detects none or more than 40 .INP files, an error message to that effect is displayed and control returns to the main menu.

It is recommended to have a separate sub-directory for each project under your main program directory SASHBEAN. This would

allow you to keep your data files organized in these project related sub-directories, leaving only the current project data files in the main SASHBEAN directory. The program, when preparing a list of available data files for selection, scans only the main SASHBEAN directory without looking into its sub-directories. Appendix A provides a quick reference on some DOS commands you may use to create/remove sub-directories and copy files around.

Once the list of available data sets (.INP extension files) is displayed, you may select one or more data sets for solution processing. This is done by typing the file # of the desired data set followed by the ENTER key from the keyboard. Selection of a data set is indicated by highlighting its filename. You may select one or more data sets while at this option. Upon completion of this selection process, return to the main menu by simply pressing the ENTER key. The selected ("Tagged") data sets are now available for analysis through option #3 as described below.

6.3 OPTION #3 (RUN ANALYSIS ON SELECTED DATA FILES)

Upon exit from option #2, select option #3 to process the selected data files for analysis. The screen changes to a multi-window display showing the status of analysis as it progresses. A sample screen layout of this display is shown in Figure 1. For a detailed description of these windows and the information being displayed in them, please refer to Section 8.0. After the analysis on selected data set(s) is complete, the program pauses for the user to return control to the main menu. The results from this analysis are written to appropriate output files in your working directory. Option #4, as described next, enables you to look at the contents of these result files.

6.4 OPTION #4 (SELECT AND DISPLAY OUTPUT RESULTS FILES)

Selection of this option allows the user to list, select, and display the output result files from mechanical analysis (files with .OUT extension) on the monitor screen. On invoking this option, user's working directory is scanned for available .OUT extension files, their list displayed and the user prompted to make a selection. If none or more then 40 such files are found in the directory, an appropriate error message is displayed. Type in the file # of the desired file and press ENTER to select and display the contents of this file on screen.

Once the selected file is displayed, the user is guided by a help message, at the bottom of the screen, on how to scroll the pages up and down. Press ESC key to close the displayed file and return to the displayed list for further selections. You may now select another file to display or return to the main menu by simply pressing the ENTER key. These output result files are

also standard text (ASCII) files and may also be read and/or printed using DOS commands/utilities. For a quick reference on some commonly used DOS commands, please refer to Appendix A.

6.5 OPTION #5 (CREATE/MODIFY DATA FILES FOR THERMAL ANALYSIS)

Select this option to create/modify data sets for thermal (steady-state and/or transient heat transfer) analysis. Some detailed information about the bearing application, including its lubrication system would be required to perform this data preparation and analysis. It is advisable to collect and prepare all pertinent data using a suggested form as shown in Appendix F. Once the data form is duly filled-in, it is simply a matter of keying in the numbers using this option. The layout of the data input screens is parallel to the design of this data preparation form to facilitate data entry. Data for steady-state and/or transient models may be prepared using this option. Detailed discussion on various input parameters for thermal analysis is found elsewhere in this documentation.

6.6 OPTION #6 (SELECT DATA FILE AND RUN STEADY-STATE ANALYSIS)

After preparing the data set(s) for steady-state thermal analysis, use this option to display a list of available such files (with .HT1 extension) and select one for processing. Once a list is displayed, typing the file # followed by an ENTER, selects and processes the requested data file.

The computed steady-state nodal temperatures are displayed on the monitor screen. These results are also written to an output file (same filename but with .HT3 extension) for future reference or printing out. After the analysis on the selected data set is complete, control returns to the displayed list for further selections. You may either make another selection for analysis or press ENTER to return to the main menu.

6.7 OPTION #7 (SELECT DATA FILE AND RUN TRANSIENT ANALYSIS)

Same as Option #6 but for transient analysis. On selection of Option #7, a list of available data sets for transient thermal analysis (files with .HT2 extensions) is displayed. Select a file by typing its displayed number followed by an ENTER or return to the main menu by simply pressing the ENTER key.

Before processing a data file for transient analysis, you <u>must</u> perform a steady-state analysis on the same system (using Options #5 and #6). By performing a steady-state analysis on the system, the nodal steady-state temperatures are estimated and made available to the transient model. These are then used as the initial

nodal-temperatures at time t=0 in the transient model. In the absence of such steady-state nodal temperature map, the transient analysis takes 0°F at the starting temperature for all nodes at time t=0.

When a data file is selected for transient analysis, the user is further prompted for the following two inputs.

(i) Time Interval for Temperature History Display

Enter the time interval (in seconds) you would like to see being stepped for each nodal temperature map display. For example, enter 30.0 if a nodal temperature map every 30 seconds is desired. The program is set to predict the nodal temperatures rise for the first one hour after the start time (point of lube loss disturbing the steady-state).

It should be noted here that the time step being used by the program for the time-domain solution of the transient model is different from this input, and selected internally. For example, the nodal temperatures might be computed internally every 2 seconds but upon user request displayed every 30 seconds.

(ii) Node Numbers to Display

Though your thermal model may have up to 20 node points, you may be interested to look at the temperature profiles of a few critical node points. For example, these could be the bearing raceway and oil outlet nodes. You may specify five selected node numbers to display, at this prompt.

Upon providing the above inputs, the transient analysis starts and the time-temperature profiles of the specified nodes are displayed. The display continues till the time scale of one hour (t=3600) is reached. The results displayed from this analysis are also appended to the steady-state results file for the same system for future reference or printing.

6.8 OPTION #8 (SELECT AND DISPLAY OUTPUT RESULTS FILE)

This option may be used to list, select and display the contents of any available results file from steady-state and/or transient thermal analysis. Results from the transient analysis on a system are always appended to the results file (.HT3 extension) from steady-state analysis on the same system. The procedure to use this option is exactly the same as that for option #4.

6.9 OPTION #9 (QUIT PROGRAM)

Select this option to exit the program and return to DOS prompt.

7.0 MECHANICAL ANALYSIS INPUT DATA

Upon selection of option #1 (Create/Modify Data Files for Mechanical Analysis) from the main menu, the menu display clears and the data input screen #1 for mechanical analysis is displayed. The use of this and the subsequent input screens is described in the following sections. Use your Page-Up" and "Page-Down" keys to change screens; and "Arrow", ENTER, or RETURN keys to move the cursor from one field to another on a given screen.

7.1 INPUT SCREEN #1 (USER AND FILE INFORMATION)

This screen allows the user to input general information for personal identification and reference. Data file names are also read in at this screen. The following four data fields, described individually, are available on this screen:

Field #1 (User's Name): A user name, up to 20 characters long, may be entered in the field. This name is for user's own identification and is printed out in the results file.

Field #2 (Description/Comments): The user may enter a comments line, up to 60 characters long, briefly describing the analysis. This could include information regarding the bearing application, loading, etc. and is again for user's own reference only. This line is also printed out, as it is, in the results file.

Field #3 (Retrieved Data File Name): This field enables the user to bring-up an existing (.INP extension) data file for modification and saving under the same or new name. By default, the program retrieves a file named DEFAULT.INP. This file is a copy of the last data set that was prepared using this option.

Field #4 (Save Edited Data Under File Name): Enter a file name (up to 8 characters long) to save the current data set. Do not use a period (.) in the file name. This filename could be the same name as the retrieved filename (field #3) or a new name. An input is required in this field before the program allows the user to proceed further to the next input screen. The user may, however, return to the main menu from this point by pressing the "Page Up" key on the keyboard.

7.2 INPUT SCREEN #2 (OVERALL BEARING DATA)

The following four fields, available on this input screen, allow the user to input the overall bearing data as described below:

Field #1 (Number of Rollers): Enter the total number of rollers in the bearing at this field. The program is presently set to analyze a bearing with up to 38 rollers. To allow more than 38 rollers in a bearing design, the dimensions of the subscripted variables in the common block (source code file COMMON.FOR) will have to be increased, program re-compiled and re-linked.

Field #2 (Pitch Diameter of Rollers): Enter the bearing pitch diameter (in inches) at this field.

Field #3 (Initial Contact Angle): Enter the design contact angle of the bearing (in degrees) at this field. A value of 0.0 may be used at this field to analyze a radial spherical roller bearing. A non-zero axial (thrust) load specified for a radial bearing is ignored and the given radial load is considered for analysis.

Field #4 (Mounted Axial Play): If an application calls for the bearing to be mounted with an axial play (a pre-load condition would be negative axial play), enter the amount of axial play (in inches) with an appropriate sign in this field. For example, a value of .001 (or +.001) entered in this field indicates that the bearing would be mounted with an axial play of .001 from the zero end play position. On the other hand, a value of -.001 indicates the mounted bearing to be pre-loaded by causing a relative axial deflection of .001 of the two rings into each other from the zero end play position.

For the axial play specified at this field, the program determines the induced axial thrust in the bearing as well as the axial and radial deflection of the rigid rings from the mounted position under the operating speed and load conditions.

7.3 INPUT SCREEN #3 (OPERATING SPEED AND LOAD DATA)

This screen reads the bearing rotational speed and external loading data through the following five fields:

Field #1 (Inner Ring Rotational Speed): If the inner ring of the bearing is rotating, enter the rotational speed (in RPM) of the ring at this field. For a stationary inner ring application, enter a value of 0 (zero) at this field.

Field #2 (Outer Ring Rotational Speed): Enter the rotational speed (in RPM) of the outer ring, if rotating, at this field. Enter a 0 (zero) for a stationary outer ring.

Field #3 (External Radial Load): Enter the radial load (in pounds), seen by the bearing in the given application, at this field.

Field #4 (External Axial/Thrust Load): Enter the axial (thrust)

load (in pounds) experienced by the bearing, in the given application, at this field.

Field #5 (Load Stationary Ring): If the externally applied radial load is stationary with respect to the inner ring, enter an I or i in this field. For a radial load stationary relative to the outer ring, enter an O or o (alphabets) in this field.

7.4 INPUT SCREEN #4 (ROLLER DIMENSIONAL DATA)

The roller dimensional and surface finish data is entered through this screen. The six fields available on this screen, are described below:

Field #1 (Roller Length, Face-to-Face): Enter the overall roller length (in inches), from one face to the other, at this field.

Field #2 (Roller Effective Length): Enter the roller's effective length, after accounting for the end corner radii, at this field. This would be the effective load bearing length of the roller and is generally taken to be the true (overall) roller length minus twice the roller corner radius or grinding undercut, whichever is longer.

Field #3 (Roller Diameter, Maximum): Enter the *maximum* roller diameter (in inches) at this field. For symmetrical spherical rollers this would be the diameter at the center of the roller length.

Field #4 (Roller Crown Radius): Enter the roller crown radius (in inches) at the field. This is the radius of the spherical profile given to the roller along its length and should be less than the crown radii of the inner and outer raceways.

Field #5 (Roller Surface Finish, RMS): Enter the RMS value of surface finish (in micro-inches) of the roller surface in contact with the raceways. If only an arithmetic average (referred as AA, RA, or Center-line Average) value is available, the Mobil's EHL guide book [9] suggests an approximate conversion factor of 1.3 (RMS = RA x 1.3). This correlation factor of 1.3 has been found by averaging the measured values of RMS and RA for several surface finishes.

7.5 INPUT SCREEN #5 (INNER/OUTER DIMENSIONAL DATA)

The required dimensional and surface finish data of the inner and outer rings is read at this screen through the following four fields:

Field #1 (Inner Raceway Crown Radius): Enter the radius of

curvature (in inches) of the inner raceway crown. This radius would be greater than the roller crown radius (entered at screen #4, field #4).

Field #2 (Outer Raceway Crown Radius): Enter the radius of curvature (in inches) of the outer raceway crown. This radius should also be greater than the roller crown radius (entered at screen #4, field #4).

Field #3 (Inner Raceway Surface Finish, RMS): Enter the RMS value of surface finish (in micro-inches) of the inner raceway surface. See remarks for screen #4, field #5, for data conversion from RA to RMS.

Field #4 (Outer Raceway Surface Finish, RMS): Enter the RMS value of surface finish (in micro-inches) of the outer raceway surface. See remarks for screen #4, field #5, for data conversion from RA to RMS.

7.6 INPUT SCREEN #6 (CAGE GUIDANCE AND DIMENSIONAL DATA)

The following four fields allow input of cage guidance and required dimensional data at this screen:

Field #1 (Is Cage Riding on Inner/Outer): Enter the letter I (uppercase or lowercase) in this field if the cage is inner ring guided and rides on the inner ring lands. Enter the letter O (uppercase or lowercase) if the cage is outer ring guided and rides on the outer ring lands.

Field #2 (Land Diameter of the Guiding Ring): Enter the land diameter (in inches) of the cage guiding ring. If you entered an I or i in the above field, enter the land diameter of the inner ring at this field. On the other hand, input the land diameter of the outer ring if an O or o was entered in the above field.

Field #3 (Cage Rail-Guide Ring Diametral Clearance): Enter the diametral clearance (in inches) between the cage rail and the guide ring land diameters. This would always be a non-zero positive value.

Field #4 (Total Riding Width of Cage Rails): In this field enter the total width of cage rails in sliding contact with the guide ring lands. As for most designs with cages having rails on either end, the data for this field would be the sum of the two rail widths. This information is only used by the program for estimating the amount of heat generation at these sliding land-rail contacts.

7.7 INPUT SCREEN #7 (MATERIAL PROPERTIES DATA)

The physical properties of construction materials used for the bearing rings and rollers are provided through the following six fields on this screen. The program allows up to two different materials to be specified - one for the rollers and the other for the rings (both inner and outer). For example to analyze a hybrid bearing with steel rings and ceramic rollers, enter the steel properties for the ring material and the ceramic properties for the roller material:

Field #1 (Modulus of Elasticity of Rings Material): Enter the Young's Modulus of Elasticity (in psi) for the inner and outer rings material at this field. For example, to enter a value of 29 million psi, you may either type in 29.0E6 or 29000000.

Field #3 (Poisson's Ratio of Rings Material): Value of Poisson's ratio for the rings material is to be provided in this field. A typical value used for SAE 52100 bearing steel is 0.29.

Field #4 (Poisson's Ratio of Rollers Material): Same as field #3 but for the rollers material. If rollers are made of the same material as the bearing rings, enter the same value again at this field.

Field #5 (Density of Rings Material): Enter the mass density (in lbm/in^3) of the rings material at this field. For example, the density of SAE 52100 bearing steel is taken as 0.283 lbm/in^3. Mass densities of some other bearing construction materials are given in Appendix O.

Field #6 (Density of Rollers Material): Same as field #5 but for the rollers material. If rollers are of the same material as the bearing rings, enter the same value again in this field.

7.8 INPUT SCREEN #8 (FATIGUE LIFE ESTIMATION PARAMETERS)

This screen allows the user to input the factors and other parameters required for the fatigue life estimation of the bearing raceways and it's complete assembly. The data required at the four fields is described below:

Field #1 (Stress Concentration Factor for Edge Loading): In this field the user may input a stress concentration factor. This factor is applied to the calculated lamina normal loads and contact stresses at the roller edge(s) lamina(e), if loaded. The adjusted lamina loads are then used for computing the roller "Equivalent" loads for fatigue lives estimation.

Enter a value of 1.0 if no adjustment for stress concentration due to edge loading is desired. The program output lists out the

contact stresses at each roller contact both before and after applying the specified stress concentration factor to the loaded edge lamina(e).

Field #2 (BDR Reduction Factor for the Bearing): To account for the non-centered and non-uniform roller loading, a reduction factor is used in the general mathematical formulation for the Basic Dynamic Capacity of the two raceways. For a modified line contact, this factor varies from 0.6 to 0.85. An appropriate factor, based upon the bearing design and loading, may be entered in this field.

Field #3 (Life Adjustment Material Factor): The improvements in fatigue life expectancy due to advancements in metallurgy and metal forming processes, is often accounted for by applying a material factor (greater than 1) to the fatigue lives predicted by the classical mathematical models. This factor is often determined either by actual testing or field data. Enter a value of 1.0 in this field if no material factor adjustment to the computed fatigue lives is desired.

Field #4 (Weibull Slope): Enter the value of Weibull slope to be used for the estimation of bearing L-10 fatigue life. According to Lundberg et. al. [7,8] Weibull slope is 10/9 for ball bearings and 9/8 for roller bearings. These values were based on actual fatigue test data for bearings manufactured from "Through Hardened" SAE 52100 steel. As per Palmgren [10], for commonly used bearing steels, the value of this slope lies between 1.1 and 1.5. Some modern ultra-clean steels may have lower values lying between 0.8 and 1.0. Weibull slope being a measure of the bearing fatigue life dispersion, a lower values of the slope indicates higher dispersion of fatigue life.

7.9 INPUT SCREEN #9 (LUBRICANT PROPERTIES & FRICTION COEFF.)

Physical properties and parameters of the specified lubricating oil are provided through this screen. The lubricant properties need to be specified at the expected surface temperatures of the contacting solids (inlet zone of the EHD film). In the absence of such temperature, an average of the oil inlet and outlet temperatures may be used as a good starting point temperature. The various fields available on this screen are described below:

Field #1 (Kinematic Viscosity of the Lubricant): Enter the kinematic viscosity of the lubricating oil (in cStokes) at this field. Kinematic viscosities of Mobil Jet Oil II and Shell Turbine Oil 555 have been plotted against operating temperatures and provided in Appendices I and J for a quick reference.

Field #2 (Lubricant Parameter): In this field the user would enter what is known as the Lubricant Parameter of the lubricating

oil. This single parameter combines the viscosity and pressure-viscosity properties of the lubricant and is given by the following equation:

$$LP = 10^{11} \cdot n_a \cdot ç \qquad (7.1)$$

where,

- LP = Lubricant Parameter of the lubricant at the EHD inlet temperature (sec)
- n_a = Absolute viscosity of the lubricant at EHD inlet temperature and atmospheric pressure (lbf.sec/in^2)
- ç = Pressure-Viscosity coefficient of the lubricant at the EHD inlet temperature (in^2/lbf)

Lubricant Parameter data for a majority of Mobil's premium lubricants is plotted against operating range of temperatures and available in their publication called Mobil's EHL guide book [9]. Data from other manufacturers may be available either in the form of this single parameter or separately as absolute viscosity and pressure-viscosity coefficient. Appendix K provides the Lubricant Parameter data for Mobil Jet Oil II for various operating temperatures.

Field #3 (Mass Density of the Lubricant): Enter the mass density of the lubricating oil (lbm/in^3) at this field. In many product specifications, the API (American Petroleum Institute) Gravity of the oil at 60°F is provided. This parameter is related to it's (lubricant's) specific gravity as follows:

$$\text{API Gravity (Degrees)} = \frac{141.5}{\text{Specific Gravity}} - 131.5 \qquad (7.2)$$

Or,

$$\text{Specific Gravity} = \frac{141.5}{131.5 + \text{API Gravity}} \qquad (7.3)$$

By considering the density of water at 60°F as 1 gm/cc, the density of oil at 60°F is then given by,

$$p_{60} = \frac{141.5}{131.5 + \text{API Gravity}} \text{ gm/cc} \qquad (7.4)$$

The density of oil at any other temperature, T°F, can then be estimated using the following relationship,

$$p_T = p_{60} - .00035(T - 60) \qquad (7.5)$$

where ρ_T and ρ_{60} are in gm/cc. For conversion of density units to lbm/in^3 refer to Appendix B. Appendices L and M provide charts for the density of Mobil Jet Oil II and Shell Turbine Oil 555 (in lbm/in^3) at various temperatures.

Field #4 (Lubricant's "EHD" Traction Parameter): In this field the user would provide a lubrication parameter, a pseudo coefficient of friction, of the lubricating oil. This parameter, typically lying between .045 and .08, along with other lubricant properties (the ambient absolute viscosity, pressure-viscosity coefficient, and a "transition" shear stress) are used to quantify the traction in sliding EHD contacts. Section 9.2 of Volume-II (Mathematical Formulation and Analysis) provides the mathematical details of this formulation.

Field # 5 (Lubricant's "Dry" Friction Coefficient): In this field, provide the traction coefficient to be used for estimating the traction forces at the sliding concentrated contacts under lost lubrication conditions. Refer to section 9.2 of Volume-II (Mathematical Formulation and Analysis) for a detailed discussion on this parameter.

8.0 MECHANICAL ANALYSIS STATUS WINDOWS

On selection of main menu option #3 to process the selected data files for mechanical analysis, the display changes to a multi-window display showing the status as the analysis progresses. There are ten distinct windows on this display, each displaying a specific information as described below. A screen layout of these windows is also shown in Figure 1. For easy reference, each window is being assigned a number, as shown on the layout, and referred here by that number.

Window #1: This window shows the overall status of the program execution on the current data set. As a certain "job specific" module (subroutine) of the program is accessed, a one line message to that effect is displayed. On the completion of analyses on all selected data sets, an "ANALYSIS COMPLETE" message is displayed in this window and program pauses for the user to interact and return to the main menu.

Window #2: This window shows the status of the iterative solution for the bearing radial load and deflections. Of the three column display in this window, the first column is the iteration #, the second column being the radial load required to cause the radial deflection of the rigid rings displayed in the third column. The iterations in this window continue till this radial load converges to the externally applied radial load.

Window #3: Same as window #2 but for the iterations on axial loads and deflections to match the externally applied axial load on the bearing.

Window #4: Shows the roller number being solved for equilibrium under the assigned radial and axial ring deflections. Using the bearing symmetry about a plane through the bearing axis, only the minimum required number of rollers are solved and displayed in this window.

Window #5: This window simply shows the externally applied radial load on the bearing. The iterations on radial load (as displayed in window #2) have to converge to this load within a set tolerance.

Window #6: Same as window #5 but for the externally applied axial load on the bearing.

Window #7: The top line in this window shows the name of the input data file being processed; whereas the bottom line shows the name of the output file to which the results of the current analysis would be written.

Window #8: This window has the column headers for the three column display of window #2. No updating takes place in this window.

Window #9: This window has the column headers for the three column display of window #3. No updating takes place in this window.

Window #10: This window, at the bottom of the screen, displays the date and time information. The displayed are the execution start date, followed by the execution start time and finally the actual clock time as execution progresses. These displays are helpful in estimating the execution/cpu times.

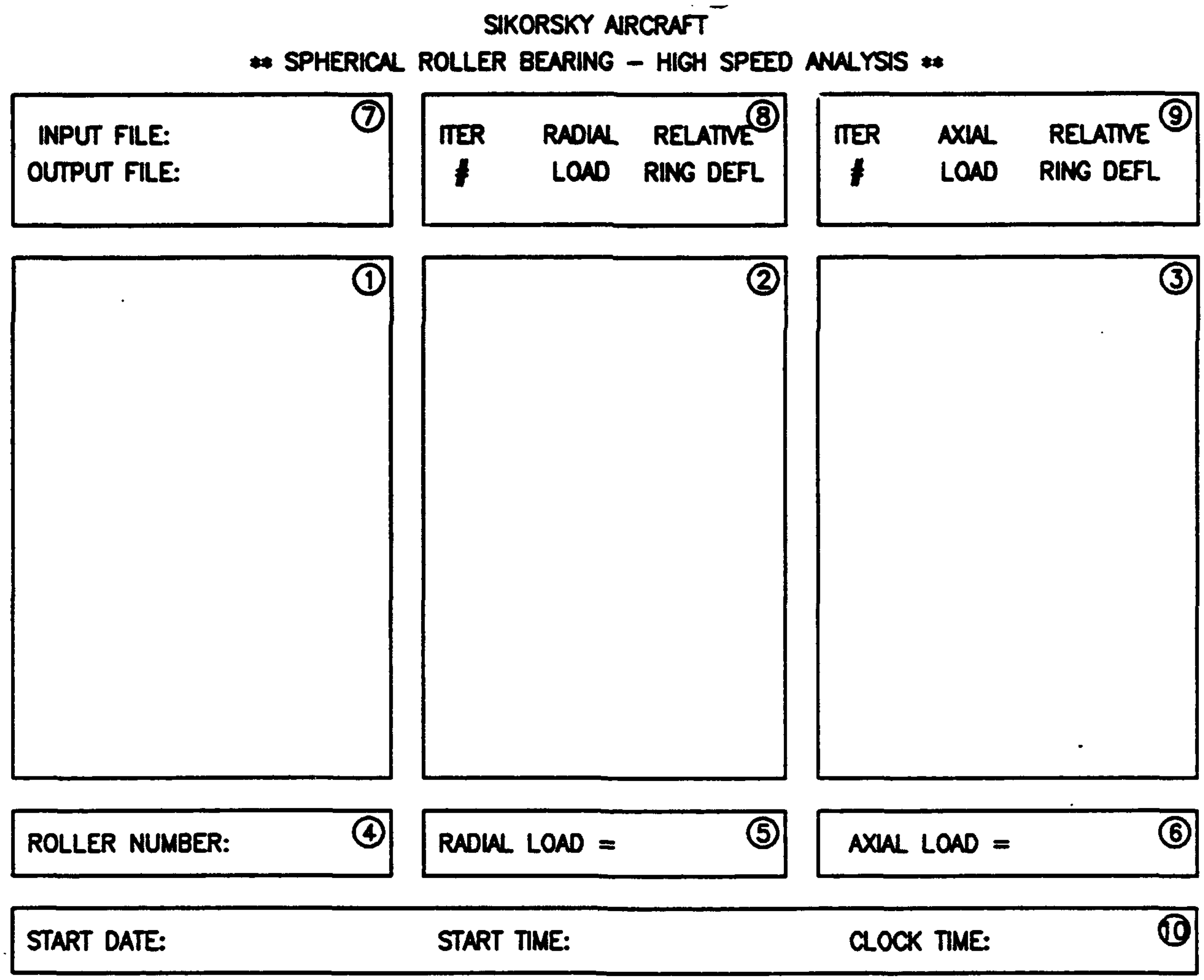


FIGURE 1
MECHANICAL ANALYSIS STATUS WINDOWS

9.0 THERMAL ANALYSIS DATA

After the completion of mechanical analysis on a bearing design (using main menu options #1 through #4), data may then be prepared for thermal (steady state/transient) analysis on the complete bearing system. As indicated earlier, some detailed information about the bearing application, including its lubrication system, would be required to set up the input data for the thermal models and estimate the expected steady-state temperature map under normal running condition, and/or time-transient temperature history for the "lost-lube" condition.

After the discretization of the bearing and it's supporting structure into axisymmetric elements of simple x-sections, node numbers are assigned to each element. The surrounding ambient air may also be considered as one or more elements and assigned valid node number(s). For a steady-state model, the lubricating fluid present at various points in the lubrication system is also considered as made up of different elements, and given node numbers accordingly. For example, the oil at the inlet manifold (with known temperature) may be considered as one element. The oil inside the bearing cavities could be another element and finally the return oil from the bearing into the oil cooler could be a separate element. For a transient model, simulating the "lost-lube" condition, the lube oil nodes of the steady-state model are replaced with air nodes. The heat transfer to the lubricating oil from the bearing and other metal nodes is then replaced with that to the air flow.

Having set up the model with elements and their node numbers, heat transfer at each node in the model with its surrounding nodes is considered and parameters set up for the input data file. Provisions to allow heat-transfer by conduction, free convection, forced convection, and mass transport are available in the program. Heat generation at each node is also considered. The heat transfer modes and their parameters are described in detail in the following sections.

9.1 HEAT TRANSFER BY CONDUCTION

When a temperature difference exists between two points of a body, heat transfer by conduction takes place. The rate of such heat flow between these two points (i,j) is given by,

$$q_{ij} = k_{ij}A_{ij}(T_i - T_j)/L_{ij} \tag{9.1}$$

where,

q_{ij} = Rate of Heat Transfer (Btu/hr)

k_{ij} = Thermal Conductivity of the Material (Btu/hr.in.°F)

A_{ij} = X-Section Area Normal to the Direction of Heat Flow (in^2)

T_i , T_j = Temperatures at the Two Points (°F)

L_{ij} = Distance between the Two Points along the direction of Heat Flow (in)

Depending upon the shape, orientation, and the materials of different elements in the model, the conduction parameters between any two node points can be written by comparing their appropriate heat conduction equations with Equation 9.1, the general heat conduction equation. Various input parameters for some common configurations are provided in Table 9.1.

9.2 HEAT TRANSFER BY FREE CONVECTION

Heat transfer from an exposed surface (for example the bearing housing surface) to the ambient air takes place by free (natural) convection. Rate of such heat transfer is given by,

$$q_{ij} = \pm h_{ij} A_{ij} |(T_i - T_j)|^e \tag{9.2}$$

where,

q_{ij} = Rate of Heat Transfer (Btu/hr)

h_{ij} = (Free) Convection Heat Transfer Coefficient (Btu/hr.in^2.°F)

A_{ij} = Surface Area of the Solid in Contact with Ambient Air (in^2)

T_i , T_j = Temperatures of the Two Media (°F)

e = An exponent lying between 1 - 1.25. e = 1 has been used in this formulation for ease of computations.

The various input data parameters, when considering heat transfer between two nodes by free (natural) convection, are thus given as per Table 9.2.

Typically, values of h_{ij}, the coefficient of free convection, lie between 6×10^{-3} - 30×10^{-3} Btu/hr.in^2·°F (5 - 25 Watts/m^2·°C). Holman [5], in section on "Natural Convection Systems" provides a detailed discussion on different methods to estimate this coefficient for various surface shapes and orientations.

9.3 HEAT TRANSFER BY FORCED CONVECTION

Heat transfer to the lubricating oil from the bearing and housing surfaces takes place by forced convection. The same mode of heat transfer also applies when air is made to flow (forced flow) over the exposed solid surfaces by suction or a fan/blower. The rate of heat transfer by forced convection is given by,

$$q_{ij} = h_{ij}A_{ij}(T_i - T_j) \tag{9.3}$$

where,

q_{ij} = Rate of Heat Transfer (Btu/hr)

h_{ij} = Forced Convection Heat Transfer Coefficient (Btu/hr.in^2.°F)

A_{ij} = Surface area of solid in contact with Flowing Fluid (in^2)

T_i, T_j = Temperatures of the Two Media (°F)

The various input parameters, when considering heat transfer between two nodes by forced convection, are given in Table 9.3.

The coefficient of heat transfer by forced convection, h_{ij}, to the fluid (oil/air) flowing through the bearing cavities may be estimated using the following equation as suggested in [2, 6],

$$h = 2.49[(N/n_k)(1 \pm D.\cos \beta/Pt)]^{1/2}.k.Pr^{1/3} \tag{9.4}$$

where,

h = Forced Convection Heat Transfer Coefficient (Btu/hr.in^2.°F)

N = Rotational speed of the bearing (RPM)

n_k = Kinematic Viscosity of the lubricating oil (cStokes). See Appendices I & J for this property of some MIL-L-23699 oils.

D = Diameter (maximum) of the rolling element (in.)

Pt = Pitch diameter of the rolling elements in the bearing (in.)

β = Contact angle of the rolling elements in the bearing (deg.)

k = Thermal Conductivity of the Fluid (Btu/hr.in.°F). Appendices P and Q list this property for some materials and fluids.

Pr = Prandtl Number of the fluid at the operating temperature. This dimensionless parameter, relating the relative thickness of the hydrodynamic and thermal boundary layers, is given by,

$$Pr = n_a.c/k \tag{9.5}$$

where,

n_a = Absolute Viscosity of the lubricating oil (lbm/in.sec).

c = Specific heat of the lubricating oil (Btu/lbm.°F)

In equation (9.4) use the negative sign when the inner is rotating, and the positive sign when the outer ring is rotating.

9.4 HEAT TRANSFER BY MASS TRANSPORT

Heat transfer also takes place along with the mass flow of a fluid from one point in the system to another. The rate of such heat transfer, caused by the fluid flow, is given by,

$$q_{ij} = p_i v_i c_i (T_i - T_j) \tag{9.6}$$

where,

q_{ij} = Rate of Heat Transfer from point i to point j within the Fluid Circuit (Btu/hr)

p_i = Mass density of the fluid at point i (lbm/in^3)

v_i = Volumetric flow rate of the fluid through point i (in^3/hr)

c_i = Specific Heat of the fluid at point i (Btu/lbm.°F)

For the conservation of mass, ensure $\Sigma v_i = 0$ for all nodes j having a fluid exchange with node i (assuming constant density). The various input data parameters, when considering heat transfer between two nodes by mass transport, are given as per Table 9.4.

9.5 HEAT GENERATION AT A NODE

The nodal heat generation rates are estimated and available after the mechanical analysis on the bearing design. The rate of heat generation in rollers, inner ring, outer ring, and the lubricant present in the cavities are estimated and listed individually in the mechanical analysis output (see page 4 of Appendix E).

When preparing data for the thermal models, assign these heat generation rates to their respective node numbers. If the load and speed environment for the lost-lube (transient) condition is different from that for the steady-state condition, two separate cases of mechanical analyses will have to be run to get the nodal heat generation rates under the two operating conditions.

The heat generation due to relative sliding at the concentrated contacts is considered equally shared by the contacting bodies. For example, of the total heat generation at the rollers-inner contacts, half the total amount is considered being generated in the inner ring and the other half in the rolling elements.

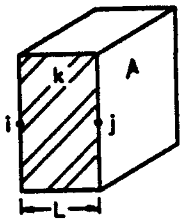
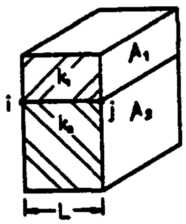
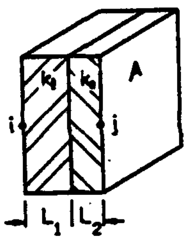
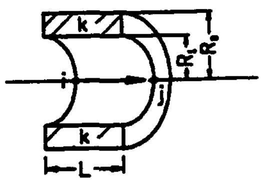
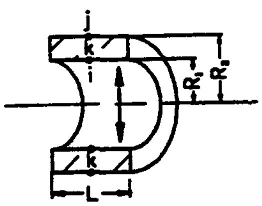
GEOMETRY/ ORIENTATION	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
	k	A	L
	$\dfrac{k_1A_1 + k_2A_2}{(A_1 + A_2)}$	$(A_1 + A_2)$	L
	$\dfrac{L_1 + L_2}{(L_1/k_1 + L_2/k_2)}$	A	$(L_1 + L_2)$
	k	$\pi(R_2^2 - R_1^2)$	L
	k	$2\pi L$	$\ln(R_2/R_1)$

TABLE 9.1

(PARAMETERS FOR HEAT TRANSFER BY CONDUCTION)

COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
h_{IJ} (Btu/hr.in^2.°F)	A_{ij} (in^2)	0 (zero)

TABLE 9.2

(PARAMETERS FOR HEAT TRANSFER BY FREE CONVECTION)

COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
h_{IJ} (Btu/hr.in^2.°F)	A_{ij} (in^2)	0 (zero)

TABLE 9.3

(PARAMETERS FOR HEAT TRANSFER BY FORCED CONVECTION)

COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
c (Btu/lbm.°F)	v_i (gallons/min)	p_i (lbm/in^3)

TABLE 9.4

(PARAMETERS FOR HEAT TRANSFER BY MASS TRANSFER)

10.0 REFERENCES

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APPENDIX - A

QUICK REFERENCE ON SOME USEFUL DOS COMMANDS

This section provides a quick reference on some DOS commands you may need to use while installing and/or using SASHBEAN software. A hard disk installation (on C: drive) under a directory named SASHBEAN has been assumed for the examples. For a different drive or directory, substitute accordingly.

A.1 EXECUTING A DOS COMMAND

Follow the following three steps to execute any DOS command:

(1) After startup or exiting a running program, wait until you see the DOS prompt C>. The letter C indicates the default drive.

(2) Type the DOS command and any other part(s) the command requires. For example, a command may have to be followed by a drive specifier or a file specification. You may type the command in uppercase or lowercase (or a combination). Use a blank space to separate the part(s) of the command line.

(3) Press the ENTER or RETURN key when finished typing the complete command line.

A.2 DRIVE SPECIFIER AND FILE SPECIFICATION

To locate a file, in addition to the filename and it's extension, DOS must also know which drive to search. The three things that DOS must know - the drive letter, the filename and the extension are together called a *file specification*. For example,

```
      filename ──────────↓      ↓───────── extension
                C:SASHBEAN.EXE
  drive letter ──↑↑──────────────────── required colon
```

The drive letter and the colon are called the *drive specifier*. You need to type the colon (:) after the drive letter as a separator. The filename and the extension immediately follow the drive specifier. Do not put any blank spaces between these three parts. When no drive specifier is provided in a file specification, the default drive (as indicated by the DOS prompt) is searched.

A.3 The FORMAT Command

This command formats (prepares) a new disk for use. It also checks the diskette for any bad spots and builds a directory to hold the file information. A new diskette must be formatted before it can be used for data storage.

Examples:

(a) **FORMAT A:** will format a Double-Density (DD) diskette in a DD drive (the A: drive) or a High Density (HD) diskette in a HD drive (the A: drive).

(b) **FORMAT A:/4** will format a 360 KB DD diskette in a 1.2 MB HD drive.

(c) **FORMAT A:/N:9/T:80** will format a 720 KB DD diskette in a 1.44 MB HD drive.

(d) **FORMAT A:/S** will format a DD disk (in DD drive) or a HD diskette (in HD drive) and install the DOS system files on the newly formatted disk.

The **/S** option may also be used with examples (b) and (c) to have the system files installed on the formatted disk.

A.4 The COPY Command

Use the COPY command to copy one or more files from one directory to another directory. The two directories (source and target) may be on same or different drives.

Examples:

(a) **COPY C:ARTBRG.OUT A:** copies the file ARTBRG.OUT from the working directory on C: drive to the working directory on A: drive under the same filename. To set your working directories, refer to the section on DOS command CHDIR.

(b) **COPY A:*.* C:** copies all files from the A: drive to the working directory on C: drive. (* is the wild card for DOS filenames and extensions and must be used with caution).

(c) To copy a file ARTBRG.OUT from your SASHBEAN directory to it's sub-directory named PROJECT1, first set your working directory to SASHBEAN (using CHDIR command as per section A.12). Then **COPY ARTBRG.OUT PROJECT1** copies the file ARTBRG.OUT from the working directory SASHBEAN to it's sub-directory PROJECT1 under the same filename. To create and remove sub-directories, refer to sections A.10 and A.11 on DOS commands MKDIR and RMDIR.

A.5 The DIR Command

Use the DIR command to find out what files are there on a disk or a particular sub-directory. It also tells you the amount of free storage available on the specified disk.

Examples:

(a) **DIR A:** displays a list (directory) of files on A: drive.

(b) **DIR** lists the directory of files in your working directory on the default drive. Typing **DIR/P** allows you to list a long directory page by page.

A.6 The DEL Command

This command may be used to delete (erase) unwanted files from a disk (fixed or floppy) directory.

Examples:

(a) **DEL A:ARTBRG.OUT** deletes the file called ARTBRG.OUT from A: drive.

(b) **DEL ARTBRG.OUT** deletes the specified file from the working directory on the default drive.

(c) **DEL *.TMP** deletes all files with extension .TMP from the working directory on the default drive. Extreme caution should be exercised when using the DOS wild card (*).

A.7 The TYPE Command

The TYPE command enables you to "look into" a file; that is, it displays the contents of a file on the screen. Text (ASCII) files are displayed in a legible format. Non-text files, such as object program files, may not be displayed because characters that are neither alphabetic nor numeric are present in such files.

Examples:

(a) **TYPE ARTBRG.OUT** displays the contents of an existing file by the name ARTBRG.OUT on screen. While the file is being displayed, you may use the PAUSE and ENTER keys on your keyboard to pause and release scrolling of the file contents respectively.

(b) **TYPE A:ARTBRG.OUT** displays the contents of the specified

file existing on A: drive. If no such filename is found, an error message is displayed.

A.8 The PRINT Command

This command allows you to print text files on a connected printer. The first time you use the PRINT command, you are prompted to enter the device (printer) name. The default is PRN, a printer connected to the first parallel port (LPT1) of the computer. Most likely this is true for your computer too. Press ENTER to select the default device and start printing.

Examples:

(a) **PRINT ARTBRG.OUT** prints the specified file on the connected printer. Make sure the printer is turned ON, paper aligned and printer made ONLINE before giving this command.

A.9 The RENAME (REN for Short) Command

Use this command to change a file's name - either its filename, its extension, or both. It is useful if you want to refer to an existing data file by a different name.

Examples:

(a) **REN ARTBRG.INP SB9999.INP** will rename the existing file ARTBRG.INP to SB9999.INP in the same directory. Using the DIR command will now list this file with it's new name.

A.10 The MKDIR (or MD for Short) Command

Use this command to create new directories and/or sub-directories to organize your files on a disk.

Examples:

(a) To create a directory by the name SASHBEAN on your C: drive, give the command **MD C:\SASHBEAN**.

(b) To create a sub-directory by the name PROJECT1 under your SASHBEAN directory, you may approach in two different ways. Typing **MD \SASHBEAN\PROJECT1** is one way to create this sub-directory. Alternately, first set your working directory to \SASHBEAN by typing **CD \SASHBEAN** (followed by ENTER) and then typing **MD PROJECT1** will create a sub-directory by the given name under the working directory SASHBEAN.

A.11 The RMDIR Command

Use the RMDIR command to remove an existing, but no longer required, sub-directory. A sub-directory can be removed only if it is empty (with no user files). Use DEL command (as shown in section A.6) to delete all existing files from the sub-directory to be removed before proceeding with this command.

<u>Examples:</u>

(a) To remove a sub-directory PROJECT1 from under the SASHBEAN directory, you may either type **RMDIR \SASHBEAN\PROJECT1** or first set your working directory to \SASHBEAN (by using the CHDIR command) and then typing **RMDIR PROJECT1** will remove the empty sub-directory PROJECT1 from under SASHBEAN directory.

A.12 The CHDIR (CD for Short) Command:

Use this command to change (set) your working directory. It is important to have your working directory set to the correct name. When using other DOS commands, in the absence of a drive specifier in a file specification, the currently set working directory on the default drive is assumed.

<u>Examples:</u>

(a) To set your working directory to SASHBEAN on C: drive, first type **C:** to make the C: drive as your default drive. Then typing CD \SASHBEAN will set the SASHBEAN directory as your working directory.

This command may also be used to find out the currently set working directory. Simply type **CD** and press ENTER. The complete "pathname" of the set working directory will be displayed.

APPENDIX - B

ENGINEERING UNITS CONVERSION FACTORS

a.	Length:	1 in = 25.4 mm
b.	Force:	1 lbf = 4.448 N
c.	Pressure/Stress:	1 lbf/in^2 (psi) = 6895 Pa = 6.895 kPa = 144 lbf/ft^2 1 atm = 14.696 psi = 101,325 Pa = 101.325 kPa
d.	Temperature:	°F = (9/5)°C + 32 °C = (5/9)(°F - 32)
e.	Work/Energy:	1 ft.lb = 1.356 Joules
f.	Power:	1 ft.lb/s = 1.356 Watts 1 H.P. = 746 Watts = 2545 Btu/hr
g.	Density:	1 lbm/in^3 = 27.68 gm/cm^3 = 27680 kg/m^3
h.	Flow Rate:	1 US Gallon/min (gpm) = 13860 in^3/hr
i.	Kinematic Viscosity:	1 Stoke = 1 cm^2/sec 1 cStoke = 1.55 x 10^{-3} in^2/sec
j.	Absolute Viscosity:	1 Poise = 1 gm/(cm.sec) 1 cPoise = 1.45 x 10^{-7} lbf.sec/in^2
k.	Pressure-Viscosity Coeff.:	1 m^2/N = 6.894 x 10^3 in^2/lbf
l.	Specific Heat:	1 Watt.sec/(kg.°C) = 2.39 x 10^4 Btu/(lbm.°F) 1 kJ/(kg.°C) = 0.239 Btu/(lbm.°F)
m.	Thermal Conductivity:	1 Watt/(cm.°C) = 57.79 Btu/(hr.ft.°F) = 4.816 Btu/(hr.in.°F) 1 Watt/(m.°C) = 4.816 x 10^{-2} Btu/(hr.in.°F)
n.	Heat Convection Coeff.:	1 Watt/m^2.°C = 1.223 x 10^{-3} Btu/hr.in^2.°F

APPENDIX - C

SAMPLE BLANK DATA PREPARATION FORM FOR MECHANICAL ANALYSIS

SEE NEXT PAGE

"SASHBEAN" BEARING ANALYSIS PROGRAM DATA SHEET			DATE:
SCREEN #	DESCRIPTION	UNITS	DATA VALUE
1	USER AND FILE INFORMATION		
	User Name (up to 20 characters)		
	Description/Comments (up to 60 char.)		
	Retrieved Data File Name		
	Save Edited Data Under File Name		
2	OVERALL BEARING DATA		
	Number of Rollers in the Bearing	-	
	Pitch Diameter of Rollers	Inches	
	Initial (Design) Contact Angle	Degrees	
	Mounted Axial Play in the Bearing	Inches	
3	OPERATING SPEED AND LOAD DATA		
	Inner Ring Rotational Speed	RPM	
	Outer Ring Rotational Speed	RPM	
	External Radial Load on the Bearing	LBS	
	External Axial (Thrust) Load on the Bearing	LBS	
	Is Load Stationary w.r.t. Inner/Outer Ring ?	I/O	
4	ROLLER DIMENSIONAL DATA		
	Roller Length, Face-To-Face	Inches	
	Roller Effective Length	Inches	
	Roller Diameter, Maximum	Inches	
	Roller Crown Radius	Inches	
	Roller Surface Finish (RMS)	Micro-Inches	
5	INNER/OUTER DIMENSIONAL DATA		
	Inner Raceway Crown Radius	Inches	
	Outer Raceway Crown Radius	Inches	
	Inner Raceway Surface Finish (RMS)	Micro-Inches	
	Outer Raceway Surface Finish (RMS)	Micro-Inches	
6	CAGE GUIDANCE AND DIMENSIONAL DATA		
	Is Cage Riding on Inner/Outer?	I/O	
	Land Diameter of the Guiding Ring	Inches	
	Cage Rail - Guide Ring Diametral Clearance	Inches	
	Total Riding Width of Cage Rails	Inches	
7	MATERIAL PROPERTIES DATA		
	Modulus of Elasticity of Inner/Outer Material	PSI	
	Modulus of Elasticity of Rollers Material	PSI	
	Poissons Ratio of Inner/Outer Material	-	
	Poissons Ratio of Rollers Material	-	
	Density of Inner/Outer Material	LBM/IN3	
	Density of Rollers Material	LBM/IN3	
8	FATIGUE LIFE ESTIMATION PARAMETERS		
	Stress Concentration Factor for Edge Loading	-	
	BDR Reduction Factor for this Bearing	-	
	Life Adjustment Material Factor	-	
	Weibull Slope	-	
9	LUBRICANT PROPERTIES & FRICTION COEFFICIENTS		
	(At Expected Surface Temperature of Solids at the	Contact)	
	Kinematic Viscosity of the Lubricant	CentiStokes	
	Lubrication Parameter of the Lubricant	Seconds	
	Mass Density of the Lubricant	LBM/IN3	
	Lubricant's "EHD" Friction Coefficient		
	Lubricant's "DRY" Friction Coefficient		
10	END OF DATA		

APPENDIX - D

SAMPLE FILLED-IN DATA PREPARATION FORM FOR MECHANICAL ANALYSIS

SEE NEXT PAGE

"SASHBEAN" BEARING ANALYSIS PROGRAM DATA SHEET DATE: 9-16-91

SCREEN #	DESCRIPTION	UNITS	DATA VALUE
1	USER AND FILE INFORMATION		
	User Name (up to 20 characters)	EPT BEARING DIVISION	
	Description/Comments (up to 60 char.)	SB-1231 UNDER FULL LOAD/SPEED	
	Retrieved Data File Name	DEFAULT	
	Save Edited Data Under File Name	STEEL-FL	
2	OVERALL BEARING DATA		
	Number of Rollers in the Bearing	-	18
	Pitch Diameter of Rollers	Inches	4.3271
	Initial (Design) Contact Angle	Degrees	16.8
	Mounted Axial Play in the Bearing	Inches	0.0
3	OPERATING SPEED AND LOAD DATA		
	Inner Ring Rotational Speed	RPM	14400
	Outer Ring Rotational Speed	RPM	0 (Zero)
	External Radial Load on the Bearing	LBS	4600
	External Axial (Thrust) Load on the Bearing	LBS	3100
	Is Load Stationary w.r.t. Inner/Outer Ring ?	I/O	O (Letter "O")
4	ROLLER DIMENSIONAL DATA		
	Roller Length, Face-To-Face	Inches	.975
	Roller Effective Length	Inches	.915
	Roller Diameter, Maximum	Inches	.650
	Roller Crown Radius	Inches	2.5126
	Roller Surface Finish (RMS)	Micro-Inches	3.90
5	INNER/OUTER DIMENSIONAL DATA		
	Inner Raceway Crown Radius	Inches	2.5509
	Outer Raceway Crown Radius	Inches	2.5850
	Inner Raceway Surface Finish (RMS)	Micro-Inches	5.20
	Outer Raceway Surface Finish (RMS)	Micro-Inches	5.20
6	CAGE GUIDANCE AND DIMENSIONAL DATA		
	Is Cage Riding on Inner/Outer?	I/O	I (Letter "I")
	Land Diameter of the Guiding Ring	Inches	4.0770
	Cage Rail - Guide Ring Diametral Clearance	Inches	.010
	Total Riding Width of Cage Rails	Inches	.463
7	MATERIAL PROPERTIES DATA		
	Modulus of Elasticity of Inner/Outer Material	PSI	29.0E6
	Modulus of Elasticity of Rollers Material	PSI	29.0E6
	Poissons Ratio of Inner/Outer Material	-	.29
	Poissons Ratio of Rollers Material	-	.29
	Density of Inner/Outer Material	LBM/IN3	.280
	Density of Rollers Material	LBM/IN3	.280
8	FATIGUE LIFE ESTIMATION PARAMETERS		
	Stress Concentration Factor for Edge Loading	-	1.50
	BDR Reduction Factor for this Bearing	-	.85
	Life Adjustment Material Factor	-	4.0
	Weibull Slope	-	1.125
9	LUBRICANT PROPERTIES & FRICTION COEFFICIENTS		
	(At Expected Surface Temperature of Solids at the	Contact)	(@ 275°F)
	Kinematic Viscosity of the Lubricant	CentiStokes	3.0
	Lubrication Parameter of the Lubricant	Seconds	2.5
	Mass Density of the Lubricant	LBM/IN3	.033
	Lubricant's "EHD" Friction Coefficient		.050
	Lubricant's "DRY" Friction Coefficient		.075
10	END OF DATA		

APPENDIX - E

SAMPLE OUTPUT FROM MECHANICAL ANALYSIS (ON SB-1231)

```
SASHBEAN - INPUT DATA  Date: 09/12/1991  Time: 14:07:23  Page: 1

 User name   : EPT BEARING DIVISION
 Description: SB-1231 (STEEL ROLLERS) WITH FULL LOAD/SPEED CONDITIONS
 Data file   : STEEL_FL.INP

OVERALL BEARING DATA:-
 Number of rollers in the bearing                 =  18
 Pitch diameter of the rollers (in.)              =   4.3271
 Initial contact angle of the rollers (deg.)      =  16.80
 Mounted axial (end) play in the bearing (in.)    =     .00000

OPERATING SPEED AND LOAD DATA:-
 Inner ring rotational speed (rpm)                =  14400.0
 Outer ring rotational speed (rpm)                =       .0
 External radial load on the bearing (lbs.)       =   4600.0
 External axial load on the bearing (lbs.)        =   3100.0
 Is load stationary w.r.t. Inner/Outer (I/O)      =  O

ROLLER DIMENSIONAL DATA:-
 Roller length, face-to-face (in.)                =    .9750
 Roller effective length (in.)                    =    .9150
 Roller diameter, maximum (in.)                   =    .6500
 Roller crown radius (in.)                        =   2.5126
 Roller surface finish (rms, micro-inches)        =   3.90

INNER/OUTER DIMENSIONAL DATA:-
 Inner raceway crown radius (in.)                 =   2.5509
 Outer raceway crown radius (in.)                 =   2.5850
 Race surface finish (rms, micro-inches)          =   5.20
 Race surface finish (rms, micro-inches)          =   5.20

CAGE GUIDANCE AND DIMENSIONAL DATA:-
 Cage guiding ring (I=inner, O=outer)       (I/O) =  I
 Guiding ring land dia. for cage riding     (in.) =   4.0770
 Ring-Cage diametral clearance              (in.) =    .0100
 Total width of cage rails - both sides     (in.) =    .4630

MATERIAL PROPERTIES DATA:-
 Modulus of Elasticity - Rings Material (psi)     =  29.0E+06
 Modulus of Elasticity - Roller Material (psi)    =  29.0E+06
 Poissons ratio - Rings Material                  =    .290
 Poissons ratio - Roller Material                 =    .290
 Mass Density - Rings Material (lbm/cu. inch)     =    .280
 Mass Density - Roller Material (lbm/cu. inch)    =    .280

FATIGUE LIFE ESTIMATION PARAMETERS:-
 Stress Concentration Factor For Edge Loading     =    1.500
 Basic Dynamic Capacity Reduction Factor          =     .850
 Life adjustment Material Factor                  =    4.000
 Weibull Slope                                    =    1.125

LUBRICANT PROPERTIES (@ Expected Operating Temperature):-
 Kinematic Viscosity of the oil (centiStokes)     =    3.000
 Lubrication Parameter of the oil (sec.)          =    2.500
 Mass Density of the oil (lbm/cu.in)              =     .033

FRICTION COEFFICIENTS:-
 "EHD" friction coefficient (Maximum)             =    .050
 "Dry" friction coefficient (Constant)            =    .075
```

SASHBEAN -- OUTPUT DATA Date: 09/12/1991 Time: 14:08:35 Page: 2

ROLLER CHARACTERISTICS:-

Roller volume (cu.in)	=	.2934
Roller weight (lbs.)	=	.0821
Mass MOI about longitudinal axis (lb.in.sec**2)	=	1.027E-05
Mass MOI about transverse axis (lb.in.sec**2)	=	2.062E-05

CAGE SPEED & DYNAMIC LOADS (@ Operating Speed & Loads):-

Cage rotational speed about the bearing axis (rpm)	=	6471.5
Centrifugal force acting on each roller (lb.)	=	191.7
Gyroscopic moment acting on each roller (in.lb)	=	8.2

INDUCED AXIAL THRUST (at the given axial play):-

For the given speed and radial load (lbs.)	=	3015.6

RING DEFLECTIONS:-

Relative axial deflection of rings (in.)	=	.000392
Relative radial deflection of rings (in.)	=	.001091

BEARING LOAD DISTRIBUTION

				INNER RACE		OUTER RACE	
ROLLER NUMBER	AZIMUTH ANGLE	MISALIGNMENT (PITCHING)	ROTATION SPEED	NORMAL LOAD	CONTACT ANGLE	NORMAL LOAD	CONTACT ANGLE
	(deg)	(deg)	(rpm)	(lbs)	(deg)	(lbs)	(deg)
1	.00	7.3E-03	-49725	1339.1	17.91	1523.3	15.71
2	20.00	8.1E-03	-49726	1229.0	17.91	1415.7	15.71
3	40.00	9.1E-03	-50165	935.6	19.00	1121.4	15.70
4	60.00	1.2E-02	-50264	585.0	19.02	766.6	14.62
5	80.00	1.2E-02	-51588	322.7	21.22	503.5	13.52
6	100.00	3.4E-03	-54405	215.9	24.51	401.6	12.42
7	120.00	-1.4E-02	-56889	180.6	26.73	364.7	12.39
8	140.00	-3.1E-02	-56924	170.2	26.76	355.6	12.37
9	160.00	-4.4E-02	-56944	163.2	26.77	345.2	12.36
10	180.00	-5.0E-02	-56952	165.9	26.78	351.1	12.35

CONTACT STRESS ANALYSIS

ROLLER NUMBER	---CONTACT ELLIPSE---- LENGTH	WIDTH	ECC.(1)	------CONTACT (2)	STRESSES------ (3)	(4)	(5)	--MAX SHEAR-- DEPTH	STRESS
	(in)	(in)	(in)	(psi)	(psi)	(psi)	(psi)	(in)	(psi)
AT THE INNER RACE CONTACTS:-									
* 1	.8187	.0150	.0482	213500	167683	213500	167683	.0059	64761
* 2	.8187	.0146	.0482	207311	162821	207311	162821	.0057	62864
* 3	.7705	.0133	.0963	188765	148255	188765	148255	.0052	57220
4	.6261	.0113	.0963	161205	126610	161205	126610	.0044	48891
* 5	.5297	.0092	.1926	132772	104279	132772	104279	.0036	40252
* 6	.3853	.0083	.3371	123228	96783	162176	127373	.0032	49280
* 7	.2408	.0092	.4334	143553	112746	215330	169120	.0036	66041
* 8	.1926	.0105	.4334	163651	128531	245477	192797	.0041	75911
* 9	.1926	.0111	.4334	172326	135344	258488	203016	.0043	80047
* 10	.1926	.0114	.4334	177501	139409	266251	209113	.0044	82519

* THE CONTACT PATTERN ENDS AT THE ROLLER EFFECTIVE EDGE(S)
AND MAY NOT BE FULLY CONTAINED ON THE ROLLER EFFECTIVE LENGTH

AT THE OUTER RACE CONTACTS:-

1	.7224	.0202	.0482	215748	169448	215748	169448	.0079	65800
2	.6742	.0197	.0482	210607	165411	210607	165411	.0077	64278
3	.6261	.0182	.0482	194181	152509	194181	152509	.0071	59258
4	.5297	.0160	.0963	171404	134620	171404	134620	.0062	52339
5	.4816	.0138	.1445	149637	117525	149637	117525	.0054	45656
6	.4334	.0127	.1926	139254	109370	139254	109370	.0050	42503
7	.4334	.0123	.1926	134696	105790	134696	105790	.0048	41090
8	.4334	.0122	.1926	133463	104821	133463	104821	.0048	40708
9	.4334	.0121	.1926	132108	103758	132108	103758	.0047	40289
10	.4334	.0122	.1926	132888	104370	132888	104370	.0047	40530

NOTES:-

(1) ECCENTRICITY OF CONTACT ELLIPSE IS THE OFFSET OF IT'S CENTER FROM THE ROLLER CENTER (ALONG ROLLER LENGTH)

(2) MAX. OF CALCULATED MAXIMUM LAMINA STRESSES FOR ROLLER

(3) MAX. OF CALCULATED MEAN LAMINA STRESSES FOR THE ROLLER

(4) SAME AS (2) BUT AFTER APPLYING A STRESS CONCENTRATION FACTOR OF 1.50 TO THE EDGE LAMINA(S), IF LOADED

(5) SAME AS (3) BUT AFTER APPLYING A STRESS CONCENTRATION FACTOR OF 1.50 TO THE EDGE LAMINA(S), IF LOADED

SASHBEAN -- OUTPUT DATA Date: 09/12/1991 Time: 14:08:36 Page: 4

E. H. D. LUBRICATION ANALYSIS

		INNER CONTACT	OUTER CONTACT
Minimum EHD film thickness (micro-inches)	=	12.40	13.93
Composite roughness (rms, micro-inches)	=	6.50	6.50
Minimum lubrication film factor, Lambda	=	1.91	2.14
Corresponding life adjustment factor	=	2.09	2.23

FATIGUE LIFE ESTIMATION

ESTIMATED L-10 FATIGUE LIVES:-

Inner raceway	712.8	Million Revs.	825.0	Hours
Outer raceway	1073.7	"	1242.7	"
Overall bearing	461.5	"	534.2	"

ADJUSTED FATIGUE LIVES:- (Appling lubri. and matl. factors)

Inner raceway	5972.0	Million Revs.	6912.1	Hours
Outer raceway	9560.5	"	11065.3	"
Overall bearing	3956.9	"	4579.7	"

HEAT GENERATION ESTIMATION

HEAT GENERATION RATES (BTU/Hr.):-		W/ Lub. Friction	W/ "Dry" Friction
Due to sliding at inner race contacts	=	15425.9	30811.2
Due to sliding at outer race contacts	=	8621.7	23987.1
Due to sliding at cage rails & inner lands	=	527.3	527.3
Due to viscous friction torque of lubricant	=	4119.7	.0
TOTAL HEAT GENERATION RATE IN THE BEARING	=	28694.6	55325.5

NODAL HEAT GENERATION FOR THERMAL ANALYSIS (BTU/Hr.):-
(Using equal division between the contacting nodes)

For the Inner ring node	=	7976.6	15669.2
For the outer ring node	=	4310.9	11993.5
For the rolling elements node	=	12023.8	27399.1
For the Cage/Retainer node	=	263.6	263.6
For the lubricating oil node in the bearing	=	4119.7	.0
TOTAL HEAT GENERATION RATE FOR ALL NODES	=	28694.6	55325.5

SUMMATION OF HERTZ CONTACT AREA/EHD FILM THICKNESS RATIOS:-

For all the Rollers at Inner race contacts	=	6228.3 in.
For all the Rollers at Outer race contacts	=	7599.8 in.

APPENDIX - F

SAMPLE BLANK DATA PREPARATION FORM FOR THERMAL ANALYSIS (SAME FOR BOTH STEADY-STATE AND TRANSIENT ANALYSIS)

SEE NEXT PAGE

PROJECT: MODEL: STEADY-STATE/TRANSIENT FILE NAME: DATE: PAGE #:

HEAT BALANCING AT THIS NODE						EXCHANGING HEAT WITH NODE(S)				
NODE #	KNOWN TEMP(F) 0 IF UNKNOWN	HEAT GENER. (BTU/HR.)	ELEM. VOLUME (CU. INCHES)	SPECIFIC HEAT (BTU/LBM-°F)	MASS DENSITY (LBM/CU.INCH)	NODE #	MODE	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"

HEAT TRANSFER MODES: 1 = CONDUCTION, 2 = FREE CONVECTION, 3 = FORCED CONVECTION, 4 = MASS TRANSPORT

APPENDIX - G

SAMPLE FILLED-IN DATA PREPARATION FORM FOR THERMAL (STEADY-STATE) ANALYSIS

SEE NEXT 5 PAGES

PROJECT: SB-1231 MODEL (STEADY-STATE/~~TRANSIENT~~): Steady State FILE NAME: STEEL.HTI DATE: 8-19-91 PAGE #: 3 of 4

HEAT BALANCING AT THIS NODE						EXCHANGING HEAT WITH NODE(S)				
NODE #	KNOWN TEMP(F) 0 IF UNKNOWN	HEAT GENER. (BTU/HR.)	ELEM. VOLUME (CU. INCHES)	SPECIFIC HEAT (BTU/LBM-°F)	MASS DENSITY (LBM/CU.INCH)	NODE #	MODE	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
13 (Leg 2)	0.0	0.0	0.0	0.0	0.0	8	1	1.84	3.93	.75
						12	1	2.25	11.0	.875
						15	1	2.25	6.1	.52
						18	3	3.232	13.5	0
14 (Shell)	0.0	0.0	0.0	0.0	0.0	4	1	2.25	3.25	1.25
						7	1	2.25	4.76	1.00
						9	1	2.25	7.65	1.125
						18	3	3.232	6.30	0
15 (Leg 3)	0.0	0.0	0.0	0.0	0.0	3	1	2.25	7.96	1.5
						10	2	.0067	68.0	0
						12	1	2.25	4.91	.52
						13	1	2.25	6.1	.52
						16	1	2.25	18.9	1.5
16 (Leg 4)	0.0	0.0	0.0	0.0	0.0	3	1	2.25	7.67	.29
						10	2	.0073	52.0	0
						15	1	2.25	18.9	1.5
17 (Oil)	0.0	1250	0.0	0.0	0.0	8	3	2.09	8.10	0
						9	3	2.09	1.40	0
						11	3	2.09	2.41	0
						18	4	0.52	0	.035
						20	4	0.52	0	.035

HEAT TRANSFER MODES: 1 = CONDUCTION, 2 = FREE CONVECTION, 3 = FORCED CONVECTION, 4 = MASS TRANSPORT

PROJECT: SB-1231 **MODEL (STEADY-STATE/~~TRANSIENT~~):** Steady-State **FILE NAME:** STEEL.HTL **DATE:** 8/19/91 **PAGE #:** 4 of 4

HEAT BALANCING AT THIS NODE						EXCHANGING HEAT WITH NODE(S)				
NODE #	KNOWN TEMP(F) 0 IF UNKNOWN	HEAT GENER. (BTU/HR.)	ELEM. VOLUME (CU. INCHES)	SPECIFIC HEAT (BTU/LBM-°F)	MASS DENSITY (LBM/CU.INCH)	NODE #	MODE	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
18 (0:1)	0.0	4073.0	0.0	0.0	0.0	1	3	3.232	42.6	0
						2	3	"	30.0	0
						3	3	"	23.12	0
						4	3	"	28.0	0
						5	3	"	18.23	0
						9	3	"	6.3	0
						13	3	"	13.5	0
						14	3	"	6.3	0
						17	4	.52	0	.035
						19	4	.52	-.40	.035
						20	4	.52	+.40	.035
19 (0:1)	0.0	-11490.0	0.0	0.0	0.0	18	4	.52	+.40	.035
						20	4	.52	-.40	.035
20 (0:1)	160.0	0.0	0.0	0.0	0.0	17	4	.52	0.0	.035
(Manifold)						18	4	.52	-.40	.035
						19	4	.52	+.40	.035

HEAT TRANSFER MODES: 1 = CONDUCTION, 2 = FREE CONVECTION, 3 = FORCED CONVECTION, 4 = MASS TRANSPORT

PROJECT: SB-1231 MODEL (STEADY-STATE/~~TRANSIENT~~): Steady State FILE NAME: STEEL-HT1 DATE: 8-19-91 PAGE #: 1 of 4

HEAT BALANCING AT THIS NODE						EXCHANGING HEAT WITH NODE(S)				
NODE #	KNOWN TEMP(F) 0 IF UNKNOWN	HEAT GENER. (BTU/HR.)	ELEM. VOLUME (CU. INCHES)	SPECIFIC HEAT (BTU/LBM-°F)	MASS DENSITY (LBM/CU.INCH)	NODE #	MODE	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
1 (Roller)	0.0	11530.0	0.0	0.0	0.0	2	1	.00732	8.3	.002
						3	1	.00732	7509.0	1.0
						4	1	.00732	6243.0	1.0
						18	3	3.232	42.6	0
2 (cage)	0.0	260.0	0.0	0.0	0.0	1	1	.00732	8.3	.002
						4	1	.00732	2.94	.005
						18	3	3.232	30.0	0
3 (Outer)	0.0	4180.0	0.0	0.0	0.0	1	1	.00732	7509.0	1.0
						15	1	2.25	7.96	1.5
						16	1	2.25	7.67	.29
						18	3	3.232	23.12	0
4 (Inner)	0.0	7615.0	0.0	0.0	0.0	1	1	.00732	6243.0	1.0
						2	1	.00732	2.94	.005
						9	1	2.25	8.92	.360
						14	1	2.25	3.25	1.25
						18	3	3.232	28.0	0
5 (Hsg)	0.0	0.0	0.0	0.0	0.0	6	1	2.25	8.60	1.0
						18	3	3.232	18.23	0
6 (Hsg)	200.0	2545.0	0.0	0.0	0.0	5	1	2.25	8.6	1.0
						7	1	2.25	75.4	1.0
						10	2	.00732	278.0	0
7 (Spndl)	200.0	2545	0.0	0.0	0.0	6	1	2.25	75.4	1.0
						14	1	2.25	4.76	1.0

HEAT TRANSFER MODES: 1 = CONDUCTION, 2 = FREE CONVECTION, 3 = FORCED CONVECTION, 4 = MASS TRANSPORT

PROJECT: SB-1231 MODEL (STEADY-STATE/~~TRANSIENT~~): Steady-State FILE NAME: STEEL.HT1 DATE: 8-19-91 PAGE #: 2 of 4

HEAT BALANCING AT THIS NODE						EXCHANGING HEAT WITH NODE(S)				
NODE #	KNOWN TEMP(F) 0 IF UNKNOWN	HEAT GENER. (BTU/HR.)	ELEM. VOLUME (CU. INCHES)	SPECIFIC HEAT (BTU/LBM-°F)	MASS DENSITY (LBM/CU.INCH)	NODE #	MODE	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
8 (Seal)	0.0	1250	0.0	0.0	0.0	9	1	1.80	3.14	.272
						9	1	1.929	3.38	.75
						11	1	1.80	2.50	1.0
						13	1	1.84	3.93	.75
						17	3	2.09	8.10	0
9 (Shell)	0.0	0.0	0.0	0.0	0.0	4	1	2.25	8.92	.36
						8	1	1.80	3.14	.272
						8	1	1.929	3.38	.75
						14	1	2.25	7.64	1.125
						17	3	2.09	1.40	0
						18	3	3.232	6.30	0
10 (Air)	90.0	0.0	0.0	0.0	0.0	6	2	.0073	278.0	0
						11	2	.0061	5.0	0
						12	12	.0061	11.0	0
						15	2	.0067	68.0	0
						16	2	.0073	52.0	0
11 (Hsg)	0.0	0.0	0.0	0.0	0.0	8	1	1.80	2.5	1.0
						10	2	.0061	5.0	0
						12	1	2.25	5.0	1.03
						17	3	2.09	2.41	0
12 (Hsg)	0.0	0.0	0.0	0.0	0.0	10	2	.0061	11.0	0
						11	1	2.25	5.0	1.03
						13	1	2.25	11.0	.875
						15	1	2.25	4.91	.52

HEAT TRANSFER MODES: 1 = CONDUCTION, 2 = FREE CONVECTION, 3 = FORCED CONVECTION, 4 = MASS TRANSPORT

APPENDIX - H

SAMPLE FILLED-IN DATA PREPARATION FORM FOR THERMAL (TIME-TRANSIENT) ANALYSIS

SEE NEXT 3 PAGES

PROJECT: [illegible] MODEL (~~STEADY-STATE~~/TRANSIENT): Transient FILE NAME: STEEL.HT2 DATE: 8/20/91 PAGE #: 1 of 3

HEAT BALANCING AT THIS NODE						EXCHANGING HEAT WITH NODE(S)				
NODE #	KNOWN TEMP(F) 0 IF UNKNOWN	HEAT GENER. (BTU/HR.)	ELEM. VOLUME (CU. INCHES)	SPECIFIC HEAT (BTU/LBM-°F)	MASS DENSITY (LBM/CU.INCH)	NODE #	MODE	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
1 ([illegible])	0.0	21057.0	5.283	.112	.283	2	1	.00732	8.3	.002
						3	1	.00732	5880.0	1.0
						4	1	.00732	4240.0	1.0
						10	3	.262	42.60	0
2 (cage)	0.0	260.0	1.24	.112	.283	1	1	.00732	8.3	.002
						4	1	.00732	2.94	.005
						10	3	.262	30.0	0
3 (Outer)	0.0	10377.0	5.982	.112	.283	1	1	.00732	5880.0	1.0
						15	1	2.25	7.96	1.5
						16	1	2.25	7.67	.29
						10	3	.262	23.12	0
4 ([illegible])	0.0	10940.0	5.112	.112	.283	1	1	.00732	4240.0	1.0
						2	1	.00732	2.94	.005
						9	1	2.25	8.92	.36
						14	1	2.25	3.25	1.25
						10	3	.262	28.0	0
5 ([illegible])	0.0	0.0	18.365	.112	.283	6	1	2.25	8.60	1.0
						10	3	.262	18.23	0
6 ([illegible])	200.0	2545.0	380.0	.112	.283	5	1	2.25	8.60	1.0
						7	1	2.25	75.4	1.0
						10	2	.00732	278.0	0
7 ([illegible])	200.0	2545.0	57.1	.112	.283	6	1	2.25	75.4	1.0
						14	1	2.25	4.76	1.0

HEAT TRANSFER MODES: 1 = CONDUCTION, 2 = FREE CONVECTION, 3 = FORCED CONVECTION, 4 = MASS TRANSPORT

PROJECT: SB-1231 MODEL (~~STEADY-STATE~~/TRANSIENT): Transient FILE NAME: STEEL.HT2 DATE: 8/20/91 PAGE #: 2 of 3

HEAT BALANCING AT THIS NODE						EXCHANGING HEAT WITH NODE(S)				
NODE #	KNOWN TEMP(F) 0 IF UNKNOWN	HEAT GENER. (BTU/HR.)	ELEM. VOLUME (CU. INCHES)	SPECIFIC HEAT (BTU/LBM-°F)	MASS DENSITY (LBM/CU.INCH)	NODE #	MODE	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
8 (Seal)	0.0	1250	1.90	.191	.116	9	1	1.80	3.14	.272
(Ceramic)						9	1	1.929	3.38	.75
						11	1	1.80	2.50	1.0
						13	1	1.84	3.93	.75
						10	3	.262	8.10	0
9 (Steel)	0.0	0.0	13.152	.112	.283	4	1	2.25	8.92	.36
						8	1	1.80	3.14	.272
						8	1	1.929	3.38	.75
						14	1	2.25	7.64	1.125
						10	3	.262	1.40	0
						10	3	.262	6.30	0
10 (Air)	90.0	0.0	10E12	.240	.36E-4	6	2	.0073	278.0	0
						11	2	.0061	5.0	0
						✓12	2	.0061	11.0	0
						15	2	.0067	68.0	0
						16	2	.0073	52.0	0
						1	3	.262	42.60	0
						2	3	.262	30.0	0
						3	3	.262	23.12	0
						4	3	.262	28.0	0
						5	3	.262	18.23	0
						8	3	.262	8.10	0
						9	3	.262	1.40	0
						9	3	.262	6.30	0
						11 13	3 3	.262 .262	2.41 13.50	0 0

HEAT TRANSFER MODES: 1 = CONDUCTION, 2 = FREE CONVECTION, 3 = FORCED CONVECTION, 4 = MASS TRANSPORT

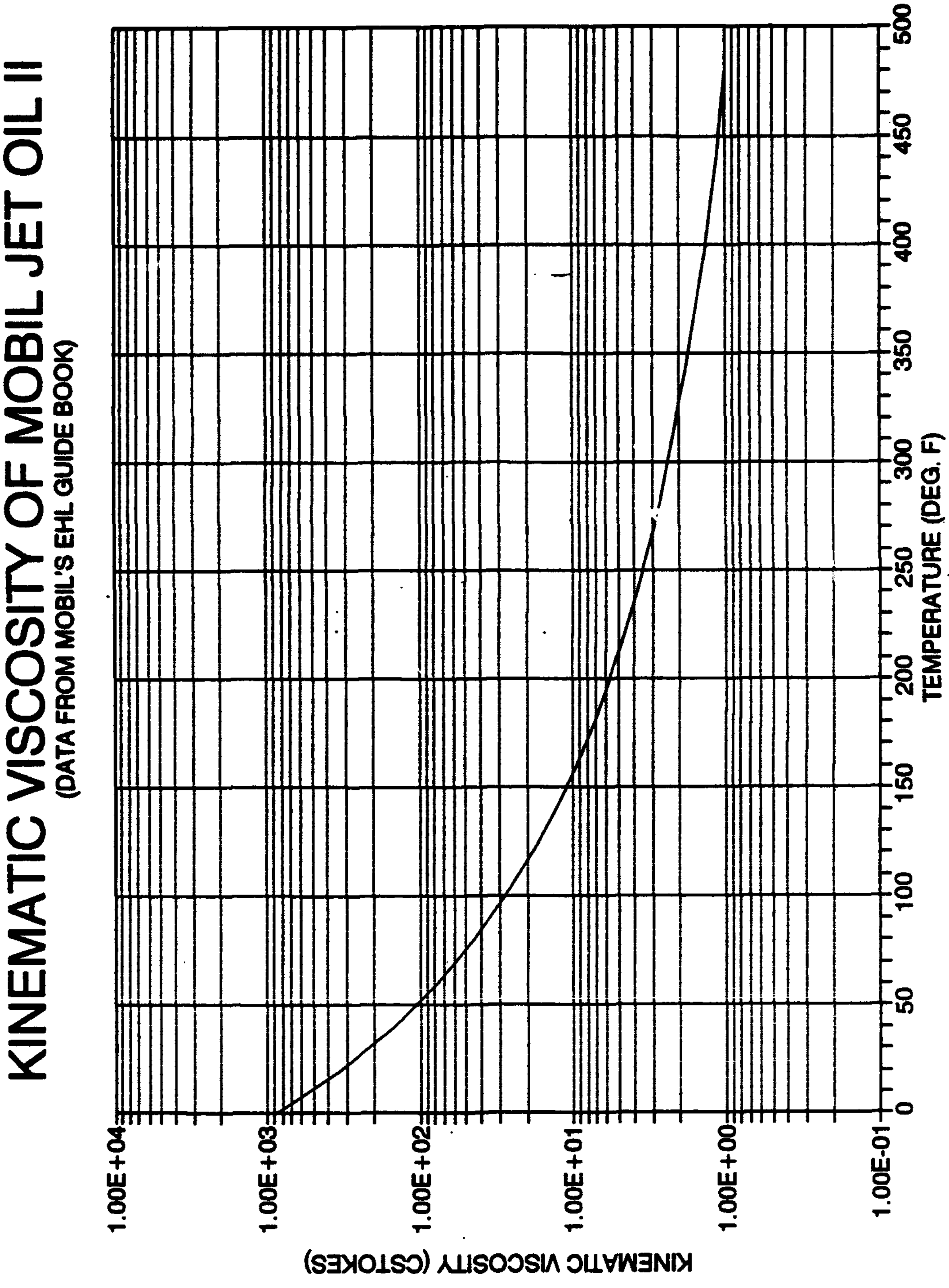
PROJECT: SB-1231 MODEL (~~STEADY-STATE~~/TRANSIENT): Transient FILE NAME: STEEL.HT2 DATE: 8/20/91 PAGE #: 3 of 3

HEAT BALANCING AT THIS NODE						EXCHANGING HEAT WITH NODE(S)				
NODE #	KNOWN TEMP(F) 0 IF UNKNOWN	HEAT GENER. (BTU/HR.)	ELEM. VOLUME (CU. INCHES)	SPECIFIC HEAT (BTU/LBM-°F)	MASS DENSITY (LBM/CU.INCH)	NODE #	MODE	COEFFICIENT "C"	PARAMETER "A"	PARAMETER "L"
10 (Cont.)	90.0	0.0	10E12	.240	.36E-4	14	3	.262	6.30	0
11 (Hsg)	0.0	0.0	3.834	.112	.283	8	1	1.80	2.5	1.0
						10	2	.0061	5.0	0
						12	1	2.25	5.0	1.03
						10	3	.262	2.41	0
12 (Hsg)	0.0	0.0	8.588	.112	.283	10 11	2 1	.0061 2.25	11.0 5.0	0 1.03
						13	1	2.25	11.0	.875
						15	1	2.25	4.91	.52
13 (Hsg)	0.0	0.0	8.934	.112	.283	8	1	1.84	3.93	.75
						12	1	2.25	11.0	.875
						15	1	2.25	6.1	.52
						10	3	.262	13.5	0
14 ([illegible])	0.0	0.0	8.715	.112	.283	4	1	2.25	3.25	1.25
						7	1	2.25	4.76	1.0
						9	1	2.25	7.65	1.125
						10	3	.262	6.30	0
15 (Hsg)	0.0	0.0	46.925	.112	.283	3	1	2.25	7.96	1.5
						10	2	.0067	68.0	0
						12	1	2.25	4.91	.52
						13	1	2.25	6.1	.52
						16	1	2.25	18.9	1.5
16 (Hsg)	0.0	0.0	33.11	.112	.283	3	1	2.25	7.67	.29
						10	2	.0073	52.0	0
						15	1	2.25	18.9	1.5

HEAT TRANSFER MODES: 1 = CONDUCTION, 2 = FREE CONVECTION, 3 = FORCED CONVECTION, 4 = MASS TRANSPORT

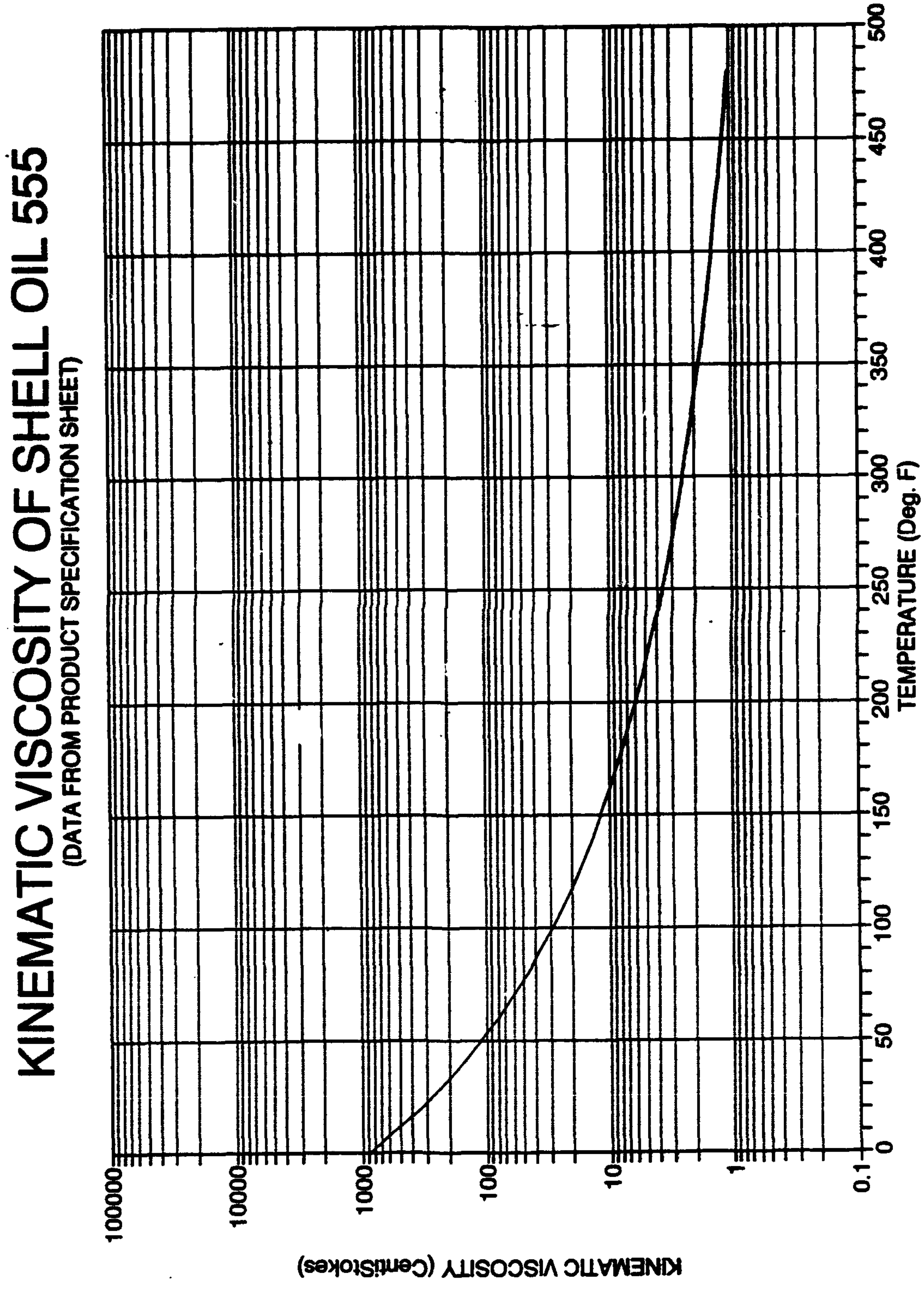
APPENDIX - I

KINEMATIC VISCOSITY DATA FOR MOBIL JET OIL II



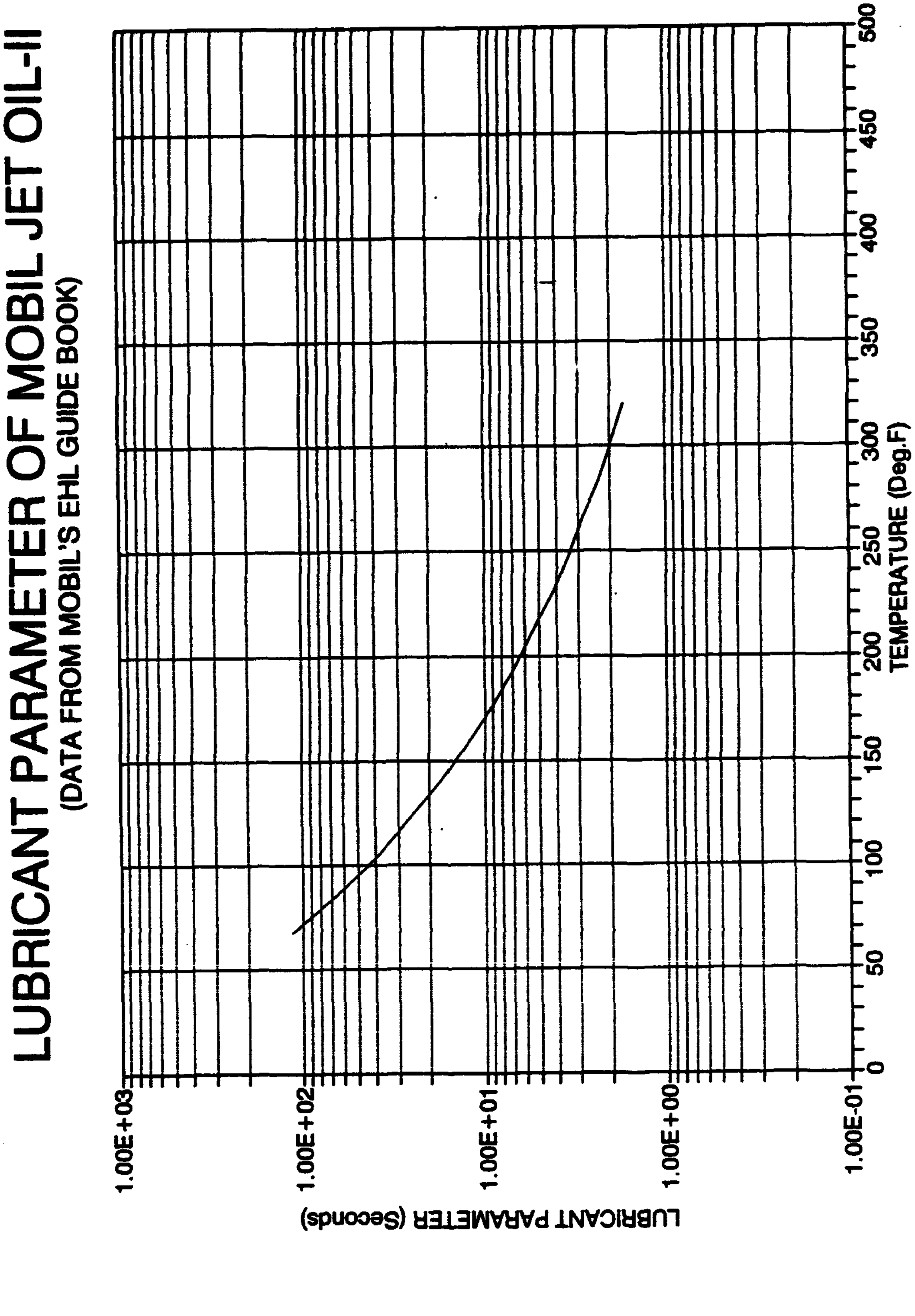
APPENDIX - J

KINEMATIC VISCOSITY DATA FOR SHELL TURBINE OIL 555



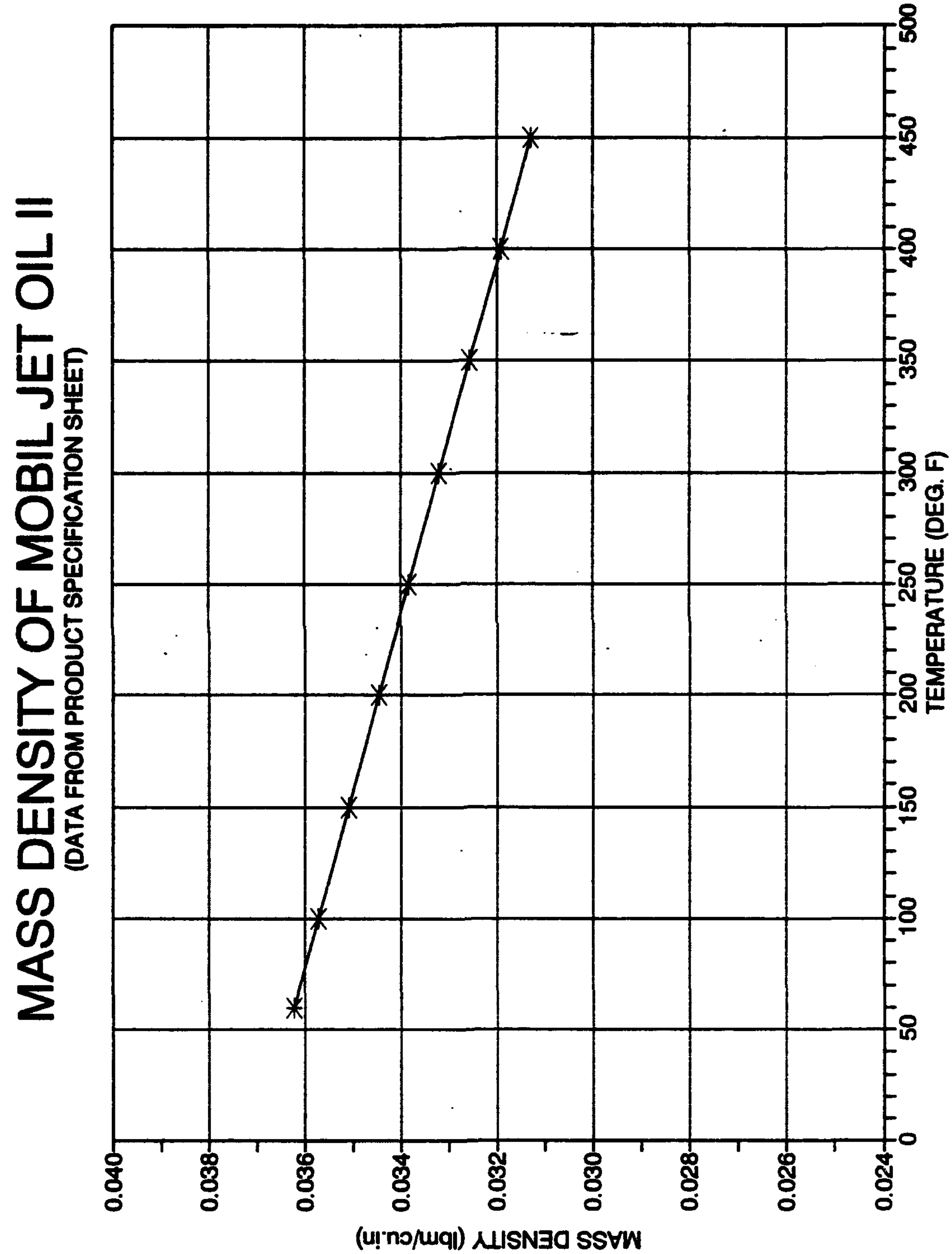
APPENDIX - K

LUBRICANT PARAMETER DATA FOR MOBIL JET OIL II



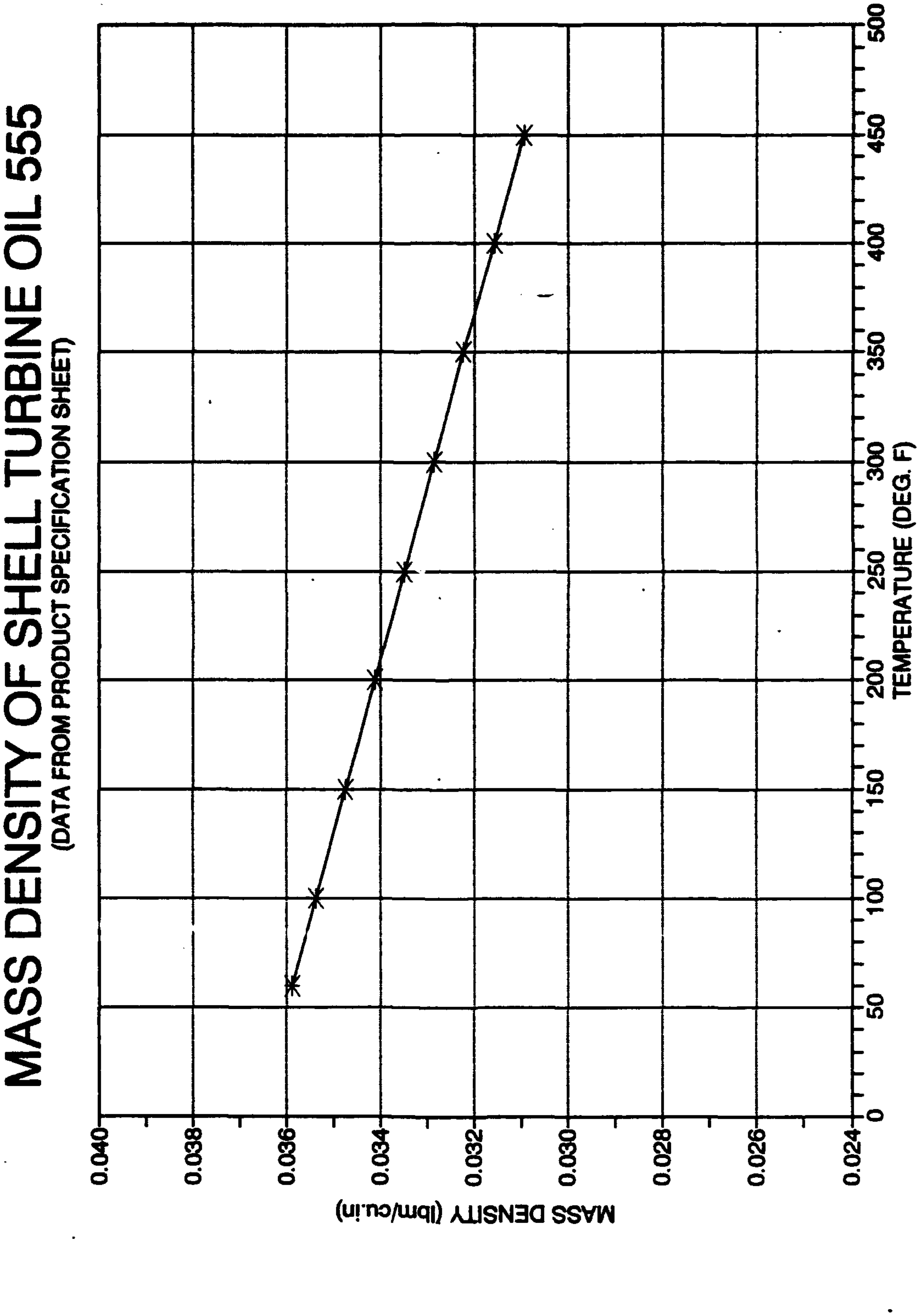
APPENDIX - L

MASS DENSITY DATA FOR MOBIL JET OIL II



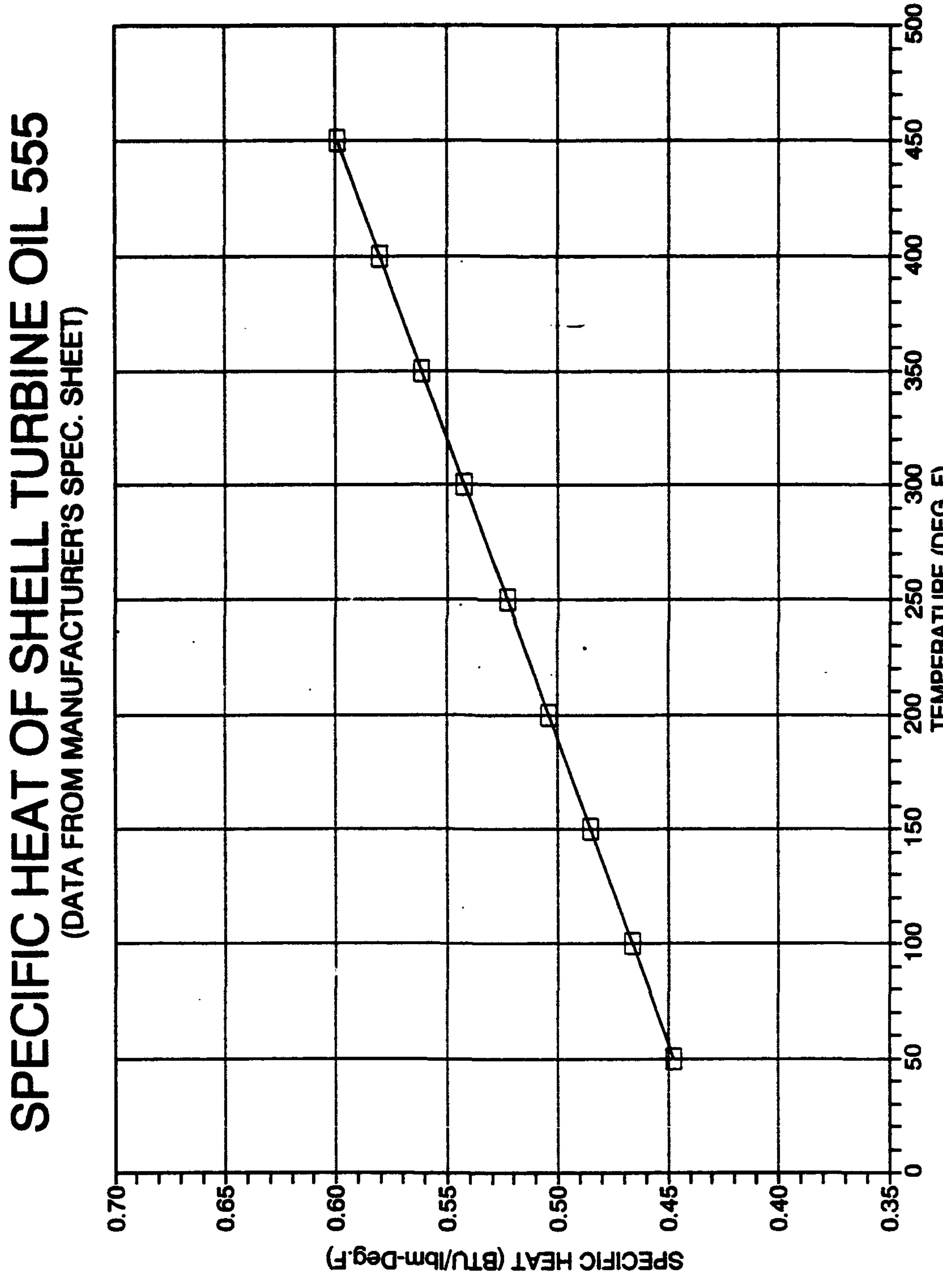
APPENDIX - M

MASS DENSITY DATA FOR SHELL TURBINE OIL 555



APPENDIX - N

SPECIFIC HEAT DATA FOR SHELL TURBINE OIL 555



APPENDIX - O

PHYSICAL PROPERTIES OF SOME METALS/CERAMICS (@ 70 °F)

MATERIAL	SP. HEAT (Btu/lbm.°F)	DENSITY (lbm/in^3)
ALUMINUM - PURE	0.214	0.098
ALUMINUM ALLOYS - AVG.	0.209	0.098
BRASS (70% Cr, 30% Zn)	0.092	0.308
BRONZE (75%Cu, 25% Sn)	0.082	0.313
CARBON STEELS - AVG.	0.114	0.282
CHROME STEELS - AVG.	0.109	0.283
COPPER - PURE	0.092	0.323
Cr-Ni STEELS - AVG.	0.110	0.283
MAGNESIUM - PURE	0.242	0.063
NICKEL - PURE	0.107	0.322
NICKEL STEELS - AVG.	0.109	0.295
Ni-Cr (80% Ni, 20% Cr)	0.106	0.300
Ni-Cr (90% Ni, 10% Cr)	0.106	0.313
TUNGSTEN STEELS - AVG.	0.105	0.291
WROUGHT IRON (0.5% C)	0.110	0.284
ZINC - PURE	0.092	0.258
CERAMIC - Silicon Nitride	0.191	0.116
CERAMIC - Silicon Carbide	0.191	0.116

APPENDIX - P

THERMAL CONDUCTIVITY OF SOME METALS/CERAMIC/FLUIDS

METALS/CERAMIC	THERMAL CONDUCTIVITY (Btu/hr.in.°F) @				
	32°F	212°F	392°F	572°F	752°F
M-52100 STEEL	2.53	2.36	2.26	2.12	1.88
M-50 TOOL STEEL	2.02	1.93	1.88	1.83	1.69
Cr-Ni STEELS - AVG	0.77	0.82	0.82	0.92	0.92
ALUMINUM ALLOYS	8.04	8.93	9.58	-	-
MAGNESIUM ALLOYS	2.50	2.99	3.56	4.00	-
CERAMIC - Si_3N_4	1.56	1.41	1.28	1.16	1.05

LIQUIDS	THERMAL CONDUCTIVITY (Btu/hr.in.°F) @				
	68°F	176°F	248°F	284°F	320°F
LUBRICATING OILS	.0072	.0067	.0065	.0064	.0064
WATER (SATURATED)	.0291	.0324	.0330	.0330	.0327

APPENDIX - Q

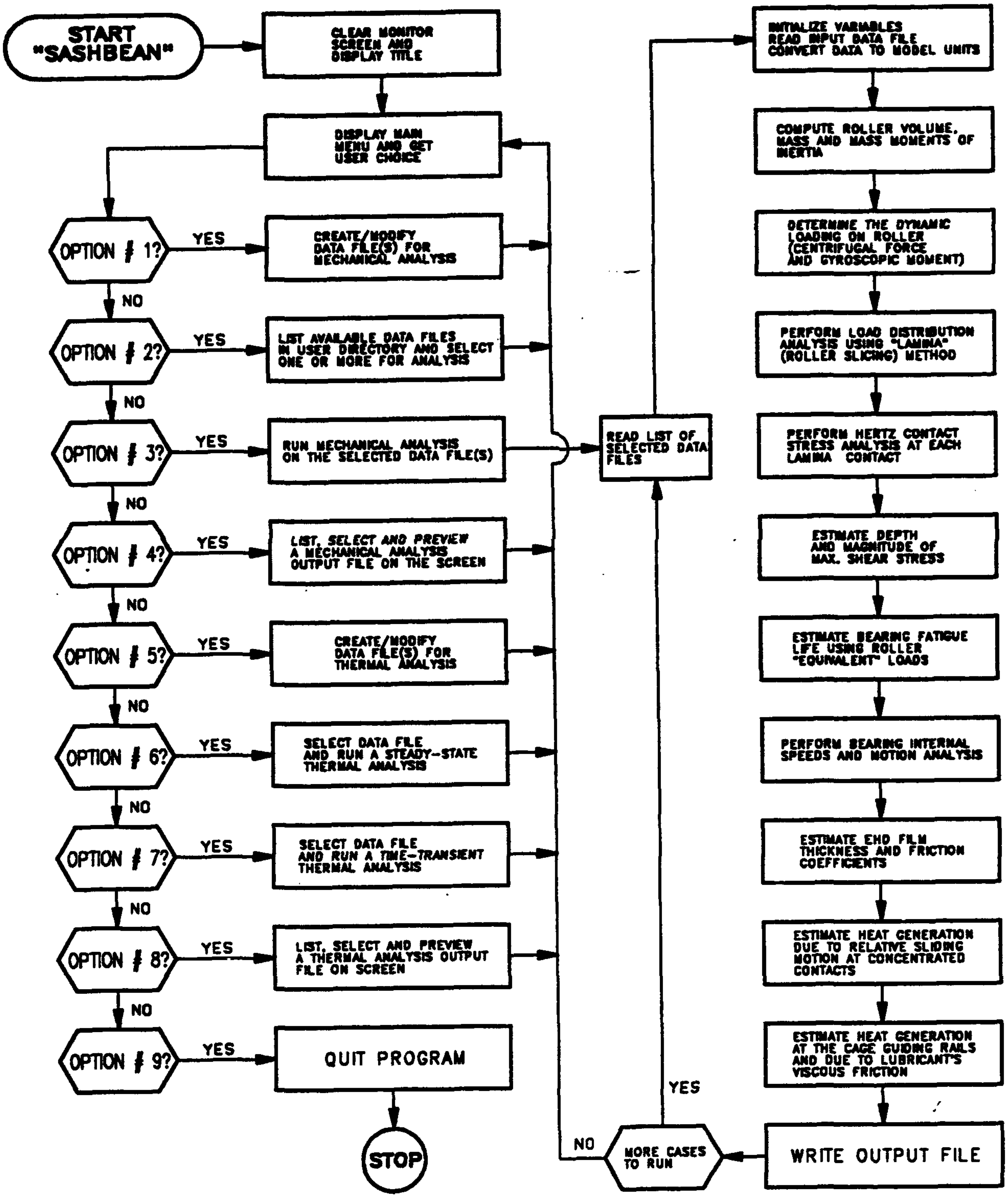
PHYSICAL PROPERTIES OF AIR AT ATMOSPHERIC PRESSURE*

TEMP.	SPECIFIC HEAT	MASS DENSITY	THERMAL CONDUCTIVITY
°F	(Btu/lbm.°F)	(lbm/in^3)	(Btu/hr.in.°F)
80	0.2404	4.25E-05	1.264E-03
170	0.2412	3.61E-05	1.446E-03
260	0.2423	3.19E-05	1.620E-03
350	0.2439	2.83E-05	1.785E-03
440	0.2461	2.55E-05	1.944E-03
530	0.2484	2.32E-05	2.099E-03
620	0.2522	2.12E-05	2.243E-03
710	0.2542	1.96E-05	2.385E-03
800	0.2570	1.82E-05	2.518E-03

* Specific heat and thermal conductivity properties are not very pressure dependent and may be used over a wide range of pressures

APPENDIX - R

OVERALL FLOW CHART FOR THE "SASHBEAN" PROGRAM



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13. ABSTRACT *(Maximum 200 words)*

The material presented in this manual is a user's guide for the successful installation and effective use of computer program SASHBEAN. SASHBEAN is capable of analyzing high speed, single row, angular contact (including zero contact angle), spherical roller bearings. For a given set of operating conditions, the program calculates the bearing's ring deflections (axial and radial), roller deflections, contact areas and stresses, depth and magnitude of maximum shear stresses, axial thrust, rolling element and cage rotational speeds, lubrication parameters, fatigue lives, and rates of heat generation. Centifugal forces and gyroscopic moments are fully considered. The program is also capable of performing steady-state and time-transient thermal analyses of the bearing system. The program runs on an IBM compatible personal computer.

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